March 2011

Bus Emissions and Their Impact on Disadvantaged Communities

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Bus Emissions and Their Impact on Disadvantaged Communities

An Interactive Qualifying Project Report
Submitted to the Faculty of the
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science

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Date:
3 March 2011

Report Submitted to:

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Abstract

This project addresses franchised bus emissions and their impact on disadvantaged communities in Hong Kong. Using interviews, literature reviews, and data analysis, it was found that franchised bus emissions contribute significantly to roadside pollution on main roads in Hong Kong. A modified Social Deprivation Index (mSDI) was also designed, and analysis of this showed a statistically significant ($p < 0.05$) relationship between high roadside air pollution and social deprivation in the districts of Wan Chai, Central/Western, and Yau Tsim Mong.

Authorship

Section Number	Section Title	Primary Author(s)
-	Executive Summary	Ted, Katelyn, John
1	Introduction	Katelyn, John
2	Background	-
2.1	Hong Kong’s Development	Katelyn
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2.3	Public Transportation	Ted
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Acknowledgements

The authors of this project would like to thank the following individuals for their help and cooperation: Professor W.T. Hung of Hong Kong Polytechnic University, Mr. Mike Kilburn of Civic Exchange, Professor Chak Chan and Dr. NT Lau of Hong Kong University of Science and Technology, and Professor Sarah McGhee and a panel from The University of Hong Kong. Their guidance and direction have been invaluable. We would like to thank Dr. Alice Chow at the Hong Kong Institute of Education for providing the group with research materials and contacts. Lastly, we would like to thank Professor Paul Harris of the Hong Kong Institute of Education for his sponsorship as well as all other members at HKIEd who graciously provided resources for our use.

Executive Summary

In recent decades, Hong Kong has seen extensive developmental growth. This development has impacted the region both positively and negatively. As Hong Kong continues to be an economic hub of Southeast Asia, the living environment for many is on the decline. The population is continually on the rise, and with this growth comes the need for territorial expansion. The New Territories have become a haven away from the heavily polluted areas of Kowloon and Hong Kong Island for a portion of the population. Unfortunately, the remainder of the population still resides within a smaller area of Hong Kong where many of the economic opportunities remain.

The rising population has required Hong Kong to provide adequate transportation. In response, businesses and the government have devised a transportation infrastructure that includes almost all major modes of transportation. Such modes of transportation include train, bus, public light bus, and taxi. Each mode of transport has both positive and negative impacts in Hong Kong. Buses in particular have had a negative impact. Buses emit numerous air pollutants that negatively affect the air quality by raising air pollution levels in the most disadvantaged communities within Hong Kong.

This project discusses the impact of the roadside air pollution from buses and their impact on the disadvantaged communities in Hong Kong. Through research, data were gathered focusing on the contribution of buses to roadside air pollution in Hong Kong, the areas of the territory with the highest concentrations of roadside air pollution, and socioeconomic status in these aforementioned areas. These data were analyzed by the team and were further supplemented by interviews with local scholars and experts whose current research lies within the scope of this study. Roadside air pollution concentrations were analyzed and compared to previous census data in an effort to see if a correlation exists between roadside air pollution concentrations and social deprivation.

It was found that franchised buses are significant contributors to roadside air pollution. Franchised buses are those that operate under a particular company and are subjected to regulations. Based on the concentrations along the main roads, specifically Hennessy Road in Wan Chai, Des Voeux Road in Central/Western, and Nathan Road in Yau Tsim Mong, roadside air pollution is more prevalent in socially deprived areas. Using a modified Social Deprivation Index (mSDI), the team identified a relationship between socially deprived areas in the form of Tertiary Planning Units (TPUs) and pollution along the aforementioned main roads. The poorer and more disadvantaged populations are exposed to these greater roadside pollution concentrations. Furthermore, these more socially deprived populations are prone to more severe cardiac and respiratory health effects.

We hope that this preliminary research involving the most polluted districts in Hong Kong can be used as a foundation for future projects to explore the social justice aspect of roadside air pollution due to bus emissions.

1. Introduction

In recent decades, much of the developing world has undergone rapid, extensive industrial and urban development leading to increased levels of air pollution. As these regions continue to grow, concerns about the social and environmental ramifications are raised by individuals and organizations who beg for change. There are many factors which contribute to air pollution; as a result, there are many opportunities to alleviate the problem. In Hong Kong, public transportation is one substantial contributor to air pollution. Though Hong Kong is developing newer, cleaner modes of transit, there are more outdated modes, particularly buses, which continue to operate.

Public transportation, in urban areas throughout the world, is the primary means by which individuals commute and travel. In most cases, mass transportation is more environmentally friendly than private transportation. However, as is the case in Hong Kong, a single outdated bus causes more pollution than the total generated by several of the newer machines. Means of transportation reliant on combustible fuels, for example, can contribute significantly to air pollution in urban areas.

Hong Kong experienced both economic and population growth in the late twentieth century. To support this development, the region developed and continues to maintain a public transport network to move individuals as they go about their daily activities. Overall, the system is continually expanding to ensure efficient and useful transit. However, the Hong Kong buses on the whole are becoming outdated and are not stringently adhering to modern environmental standards that pertain to engine standards.

Diesel buses have a considerably more negative environmental footprint relative to other means of public transit used in Hong Kong, such as electric trains and taxis fueled by liquefied petroleum gas (LPG). Older buses which still operate on many bus routes in Hong Kong are highly polluting compared to the newer buses. The older buses contribute significantly to roadside air pollution, and their emissions impact the health of individuals who spend the majority of their lives close to the roadside.

This project highlights the impact of roadside air pollution from buses and how this negatively affects the health of Hong Kong's most disadvantaged communities and individuals. To bring the effect of the buses on public health to the forefront, this study makes use of information regarding Hong Kong's growth, its transportation system, the bus infrastructure, and environmental justice demographics. Research and data analysis are used to supplement the information gained by interviewing scholars and experts in Hong Kong. From these data and results, we created a foundation for future research regarding the impact of bus emissions on the people of Hong Kong living in socially deprived areas.

2. Background

This chapter discusses the impact of vehicular, roadside air pollution from bus emissions on Hong Kong and the pollution's contribution to the greater problem of air pollution overall. The chapter addresses a brief history of Hong Kong's development to initiate further research into Hong Kong's transportation infrastructure on a whole and to detail the infrastructure of the bus system. Additionally, Hong Kong's governmental regulations on bus emissions will be outlined and compared to other major, international cities with structured bus systems.

2.1. Hong Kong's Development

Prior to understanding the current, vehicular, roadside air pollution situation in Hong Kong Special Administrative Region (HKSAR), it is important to understand its recent development. Seen as the gateway into China, Hong Kong held a considerable draw for foreign business in the wake of the Second Anglo-Chinese War from 1856-58 when England acquired the New Territories (Hong Kong Government, 2009b, p. 422). "The population rose from 32,983 (31,463 or 95 percent Chinese) in 1851 to 878,947 (859,425 or 97.8 percent Chinese) in 1931. The Chinese influx was unexpected because it was not anticipated they would choose to live under a foreign flag" (p. 423). Throughout the next several decades, the population of Hong Kong continued its rise which impacted Hong Kong's economic and territorial development.

In the mid-twentieth century, people began viewing Hong Kong as an economic gateway into Mainland China. "The coming down of the 'bamboo curtain' after 1949 did, in turn, make Hong Kong attractive to international financiers as the gateway for tapping into the rich Chinese market" (Laquian, 1996, p. 21). The influx of foreign business resulted in a diverse and ever-growing population. A model of recent population growth can be seen below in Figure 2-1. According to the Census and Statistics Department in Hong Kong, since 1971, the population had risen by nearly three million to a total of 7,026,400 by 2009 (Census and Statistics, 2007b; Census and Statistics, 2009; Hong Kong Government, 2009c, p. 411).

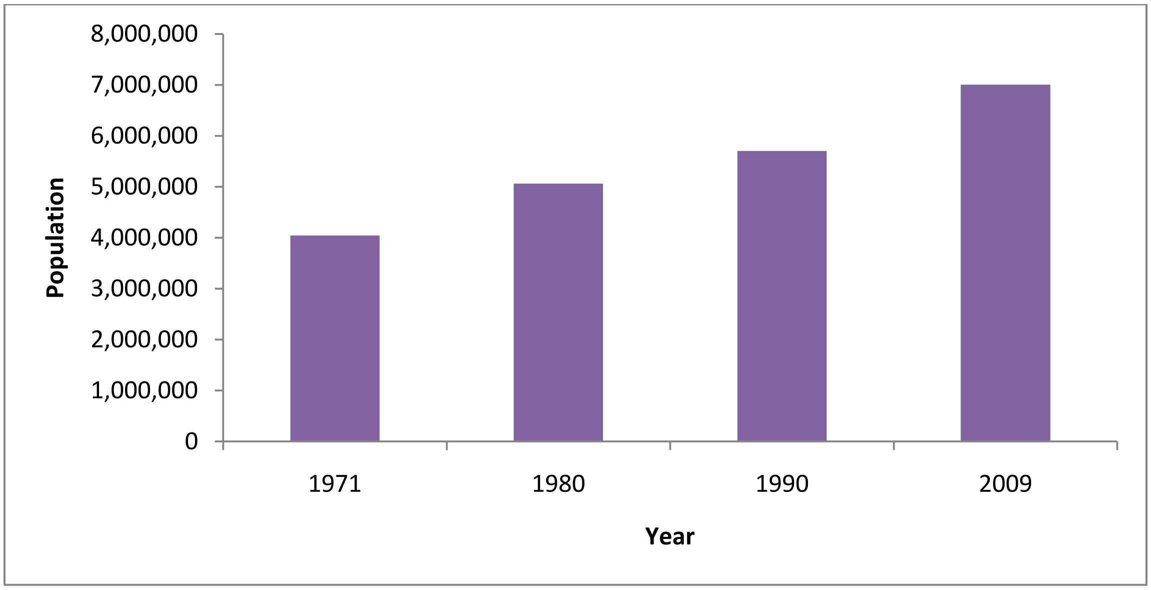

Figure 2-1: Population Growth in Hong Kong 1971-2009
(Census and Statistics, 2007; Census and Statistics, 2009)

2.2. Population on the Rise

A variety of interacting factors contributed to the rapid population growth in Hong Kong. One of the causes is increased accessibility to medical attention. Hong Kong has made health care more available for the elderly. For the aging population, there are greater opportunities to receive help. The Hong Kong Government states the following in their 2009 Yearbook regarding elderly healthcare:

> *The Department of Health has 18 elderly health centres and 18 visiting health teams to render primary health care to the elderly, improve their ability to care for themselves and encourage healthy living and their family's support. These centres provide health assessments, physical check-ups, counselling, curative treatment, health education and other healthcare services to people aged 65 and above. The visiting health teams conduct*

> *health promotion activities for the elderly and provide training for careers to improve their caring. In 2009, the elderly health centres recorded 38,678 enrolments and 174,402 attendances for health assessment and medical consultation, while the visiting health teams provided service to 279,553 client contacts* (p. 157).

With the progression of technology and the increased medical facilities, Hong Kong residents are living longer. According to the Census and Statistics Department, the number of individuals aged 65 and older had increased from 6.6% in 1981 to 12.4% in 2006. The average age has risen as well; in 2006 the average age was 39.6 as opposed to the 26.3 in 1981 (Census and Statistics, 2007a, p. 9).

During the end of the twentieth century, the Hong Kong government realized the impact of the population growth, and in 1991, it drafted together the Metroplan (Eason, 1996, p.3). The Metroplan provided a framework for the Hong Kong government to regulate development in the Metro Area consisting of Hong Kong Island West, Hong Kong Island East, Hong Kong Island South, West Kowloon, South East Kowloon, Central and East Kowloon, and Tsuen Wan and Kwai Tsing (Planning Department, 2010, para. 3). In 2006, the Census and Statistics Department of Hong Kong accounted for a total population of 6,864,346 (2007). The department began developing strategies to spread the population outside of the densely populated Metro Area.

Originally, the plan to decentralize the population sounded promising. Unfortunately as of 2009, the percentage of people living in the Metro Area is still greater than that of those living in the New Territories. The distribution of the population's location is shown in Figure 2-2. Because the Metro Area is so small, compared to that of the New Territories, this means that there is still a high population density in the Metro Area. Figure 2-3 depicts the New Territories in green with the remaining Metro Area in the light gray. More than half of the population of Hong Kong live and work in the heart of the city while many others live outside of the City Center and commute to the Center for work.

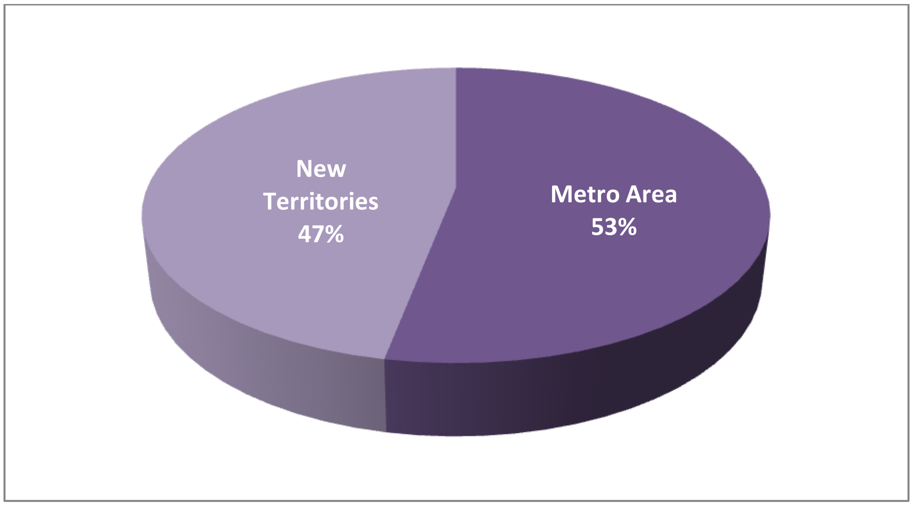

Figure 2-2: Population Distribution of Hong Kong in 2009
(Hong Kong Government, 2009c, p. 411; Information Services Department, 2010, para. 5)

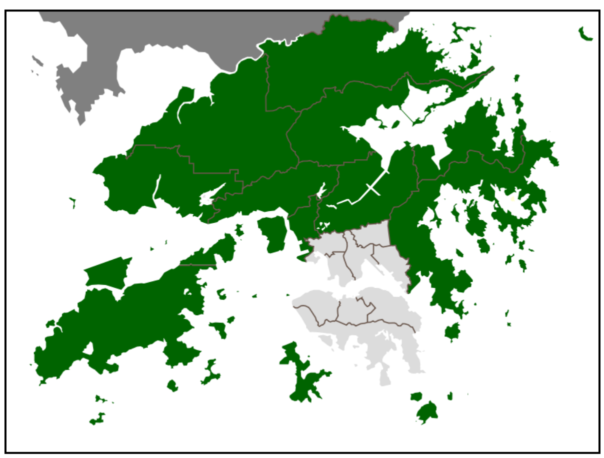

Figure 2-3: Map of Hong Kong highlighting the New Territories
(Wikimedia Commons, 2011)

With the rise of the population in the New Territories and the concentrated population in the heart of Hong Kong, it is necessary to provide adequate, public transportation. Accordingly, the usage of the public transportation system has increased. To accommodate the need for transit, Hong Kong has a public system that includes nearly all the major modes of transportation (Wang, 2011, para. 2). Hong Kong desires sustainable methods to develop its transit network, and it is using the 1987 World Commission on Environment and Development's definition of sustainability stating "meeting the need of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987, para. 2). With the need to move a large population effectively and efficiently, Hong Kong developed a mostly sustainable transportation network but some of the transportation modes still contribute significantly to air pollution.

2.3. Public Transportation

Hong Kong has one of the most advanced public transit systems in the world. This region also has the highest rate of public transport use in the world**,** with 90% of its inhabitants taking daily transit (Lam, 2003, p. iii). There are many different transportation choices in Hong Kong, including train, bus, minibus, and taxi. One of the efficient features of the Hong Kong public transportation network is the Octopus card, which can be used on all trains, buses, and minibuses in Hong Kong (Octopus Cards Ltd., 2011).

2.3.1. Mass Transit Railway (MTR)

The Mass Transit Railway network is the most efficient means of public transportation throughout Hong Kong**.** The MTR, operated by the MTR Corporation Limited, provides transport not only in Hong Kong Island, but also to the Kowloon Peninsula and the New Territories. According to the Hong Kong Transport Department, the MTR has ten railway lines, which include 84 railway stations and 68 light rail stops (Transport Department, 2010). Presently, the MTR system consists of Kwun Tong Line, Tsuen Wan Line, Island Line, Tung

Chung Line, Tseung Kwan O Line, East Rail Line, West Rail Line, Ma On Shan Line, and Disneyland Resort Line. There 84 stations make up over 170 kilometers of routes which combined transport an average of about 3.7 million passengers per weekday. A standard fare for an adult ranges from $3.5 HKD to $51 HKD. The MTR, unlike buses, minibuses, and taxis, is electrically powered, though most of that electricity is generated through burning coal at offshore power plants (Business Environmental Council, 2003, p. 1). The MTR System also covers a light rail network in the New Territories (Transport Department, 2010). The system encompasses 36.2 kilometers of double track with 68 stops and 125 single-deck light rail cars. Adult single journey ticket fares range from $4 HKD to $6 HKD. Approximately 390,000 passengers travel on the light rail network daily.

2.3.2. Franchised Bus

There are five major franchised bus companies in Hong Kong: Kowloon Motor Bus/Long Win Bus, Citybus/Cityflyer, New World First Bus, New Lantau Bus, and MTR Bus. Out of these five, the three largest bus fleets are the Kowloon Motor Bus Company (KMB), New World First Bus Services Limited (NWFB), and Citybus Limited. These three bus fleets constitute the majority of franchised buses in Hong Kong. According to the Hong Kong Transport Department Statistics, KMB combined with Long Win Bus, operates 396 bus routes in Kowloon and the New Territories and 62 cross-harbor routes (Transport Department, 2010). Fares range from $2.5 to $11.8 for urban routes, from $1.7 to $40 for the New Territories routes and from $8.4 to $35.6 for the cross-harbor routes. With a fleet of 3,880 buses, mostly double-deckers, KMB is one of the largest road passenger transport providers in the Southeast Asia. The total licensed fleet carries about 2.64 million passengers a day. NWFB operates 55 Hong Kong Island routes, 34 cross-harbor routes and eight routes serving Kowloon and Tseung Kwan O, and carries 471,000 passengers daily using a fleet of 715 buses. Fares range from $3.2 to $9.8 for Hong Kong Island routes, $3.4 to $7.9 for Kowloon and Tseung Kwan O routes and $8.4 to $35.6 for the cross-harbor routes. Citybus Limited operates two bus services, Citybus and Cityflyer (Transport Department, 2010). Citybus comprises 62 Hong Kong Island routes, one New Territories route and 29 cross-harbor routes. With a fleet of 761 buses, this network carries approximately 511,000 passengers a day. Fares range from $2.5 to $10.6 for Hong Kong Island routes, and from $9.3 to $32.2 for the cross-harbor routes. Citybus Limited's second bus network, Cityflyer, provides services between urban areas and the Hong Kong International Airport. This network is made up of 18 routes and 172 buses. Daily use is about 59,000 passengers and fares range from $3.5 to $48. As of 2009, there were 5,627 franchised buses registered for active use in Hong Kong. However, as of 2010, there are currently 5,955 franchised buses in Hong Kong registered for transport purposes throughout Hong Kong (Clean Air Network, 2010c, pg. 3).

2.3.3. Public Light Bus

Public Light Buses (PLBs) are minibuses with a maximum of 16 seats. PLBs are separated into two separate colors: red and green (Transport Department, 2010). Green PLBs are used for scheduled services and red for non-scheduled services. Red minibuses are free to operate anywhere, except specified restricted areas, without fixed routes or fares. There are 1,361 red minibuses in Hong Kong which service approximately 371,300 passengers daily. Green minibuses operate frequently on fixed routes and fares. By the end of June 2010, there were 2,988 green minibuses in Hong Kong servicing 71 routes on Hong Kong Island, 81 in Kowloon, and 200 in the New Territories. Green minibuses carry about 1,488,300 passengers daily (Transport Department, 2010). In August 2002, the Transport Department encouraged Public Light Bus (PLB) owners to replace their diesel PLBs by LPG or electric ones (Transport

Department, 2009, p. 8). Under the scheme, grants of $60,000 and $80,000 were awarded for replacement of diesel PLBs by LPG and electric PLBs respectively. At the end of 2009, the number of LPG PLBs was 2,682 versus 593 diesel PLBs.

2.3.4. Taxi

Taxis in Hong Kong are the last main form of public transportation, functioning in a primarily auxiliary capacity. Currently, there are approximately 15,250 urban taxis, 2,838 New Territories taxis and 50 Lantau taxis. Urban taxis are denoted by the color red, New Territories green, and Lantau blue. Combined, these taxis carry about one million passengers daily. Urban taxis operate throughout Hong Kong except Tung Chung Road and roads in south Lantau. New Territories taxis mainly operate in the northeastern and northwestern parts of the New Territories. Lantau taxis operate only on Lantau Island and Chek Lap Kok (Transport Department, 2010). Until the late 1990s, almost all taxis in Hong Kong ran on diesel fuel. In 1996, the government of Hong Kong introduced a new taxi that ran on liquefied petroleum gas (LPG) in an effort to use a cleaner alternative fuel to diesel. Due to the efficiency of this new taxi, in 1999, all new taxis were manufactured for LPG use (Transport Department, 2009, p. 7). To speed up the replacement of diesel taxis with LPG ones, from mid 2000 to the end of 2003, the government offered a cash grant for a maximum of $40,000 to each taxi owner who purchased a new LPG taxi during that period. By the end of 2004, 99% of taxis have been changed to LPG.

2.3.5. Franchised Bus Specifications

Looking more specifically into buses, there are six types of bus engines under which buses are classified. These engines are known as pre-Euro, Euro I, II, III, IV, and V, all of which use diesel as their source of fuel (KMB, 2010). The difference between the types of Euro engines is their conformity to progressive environmental regulations. For example, Euro I has poorer emission standards than Euro IV (see Table 2-1). Unfortunately, the information regarding the Pre-Euro engine standards was unavailable from the Kowloon Motor Bus Company.

Engines	Carbon Monoxide (CO) (grams per kW/h)	Hydrocarbons (HC) (grams per kW/h)	Nitrogen Oxides (NOx) (grams per kW/h)	Particulate Matter (PM) (grams per kW/h)
Euro I	4.5	1.10	8.0	0.36
Euro II	4.0	1.10	7.0	0.15
Euro III	2.1	0.66	5.0	0.10
Euro IV	1.5	0.46	3.5	0.02
Euro V	1.5	0.46	2.0	0.02

Table 2-1**:** Amount of chemical emissions from the Euro I-V standard buses (KMB, 2010)

The enactment of the Euro standards led to drastic declines in acceptable pollutant values for diesel vehicles. Particulate matter (PM) emissions standards, for example, were cut by 40% under Euro I (EPD, 2010, para. 7). Today, Euro IV is the standard for all new vehicles in Hong Kong. Using the pre-Euro standard as a baseline one can see the Euro IV engine permits 98% less particulate matter (PM) and 60% less oxides of nitrogen (see Figure 2-4). However, Euro I and pre-Euro vehicles still exist on the roads of Hong Kong today.

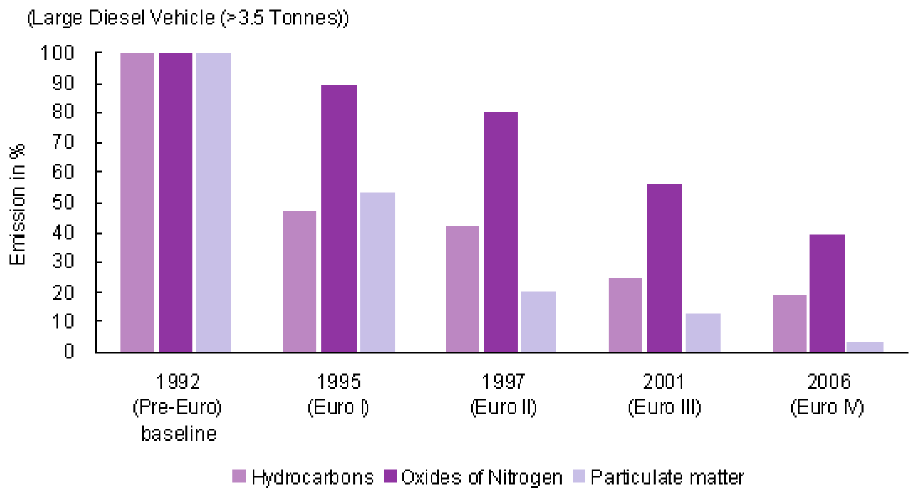

Figure 2-4**:** Percentage of emissions from Euro-standard vehicles in years 1992-2006 (Environmental Protection Department, 2010)

According to Trumbull (2007), as of 2007, 12% of buses were either Euro I or pre-Euro, and it is estimated these buses specifically are responsible for 70% of the air pollution emitted from buses (p. 53). As of 2009, 99.1% of franchised buses are using Pre-Euro, Euro I, Euro II, and Euro III engines, therefore less than 1% have met the Euro IV standard (Clean Air Network, 2010a, p. 13). Franchised buses, specifically, also contribute to 5% to all roadside RSP emissions, and 10% to all roadside NOx emissions, yet only account for 1% of vehicles in Hong Kong.

2.4. Air Pollution

All the buses in Hong Kong operate on diesel engines. Heat, generated during compression, ignites the fuel in a diesel engine. Diesel engines require a high compression ratio for a proper working process, since compression is responsible for the ignition process (Hester & Harrison, 2009, p. 3).

The chemical structure of diesel fuel consists of large hydrocarbon molecules. Diesel engines tend to be larger, heavier and have a higher cost, since they require a high compression ratio and a large surplus of air. A diesel engine needs a high surplus of air for its operation because of its poor mixing capabilities. A fuel spray, a mixture of fuel droplets and vapor, forms during the process of atomization. The combustion process occurs between fuel vapor and the surrounding air at the flame zone. This process is called diffusion combustion since the process is controlled by the diffusion of fuel vapor and air. (Fenger & Tjell, 2009, p. 127).

Pollutant emissions from vehicular transport are known to have low release heights, not higher than 10 meters above the ground. Therefore, these emissions are the major contributors to urban air pollution because they do not get diluted as fast as the emissions from tall release heights (Hester & Harrison, 2009, p. 3).

Air quality in urban areas varies greatly due to the different emission sources. Road traffic is considered to be the most significant contributor of air pollution in the cities throughout the world. However, domestic heating, industry, power generation, fugitive and re-suspended dust emissions, and long range atmospheric transport also impact air pollution levels.

2.4.1. Major Air Pollutants

Nitrogen Oxides (NOx) and Nitrogen Dioxide (NO_2)

Nitrogen from the air gets oxidized to nitrogen oxide. The overall reaction is shown below:

Equation 2-1: $$N_2 + O_2 \rightarrow 2NO$$

Nitric oxide can form nitrogen dioxide (NO_2) through oxidation process:

Equation 2-2: $$2NO + O_2 \rightarrow 2NO_2$$

Nitrogen oxides (NOx) is a collective term used to refer to two species of oxides of nitrogen: nitric oxide (NO) and nitrogen dioxide (NO_2): their concentrations vary frequently, however the sum of concentrations remains the same. Due to its relatively insoluble nature, nitrogen oxides can penetrate deep into the lungs and initiate inflammatory responses in alveoli.

After reaching the lungs, nitrogen oxides get converted into nitrate, nitrite, nitric acid and nitrous acid, which all negatively affect the mucus membranes.

Long-term exposure of nitrogen dioxide on the structure of lungs can be damaging for the cellular metabolism in the lungs and the resistance against bacterial infections. For people with asthma and bronchitis, nitrogen dioxide is especially harmful since it enhances airways responses to inhaled allergens and may result in reduced lung function. (Fenger & Tjell, 2009, p. 339)

Nitrogen dioxide might form in the engine or later in the exhaust pipe or in the atmosphere. It is a major component of chemistry in the troposphere layer which is originated from primary emissions of combustion processes and oxidation of nitrogen monoxide (NO).

Figure 2-5 shows the annual average of nitrogen dioxide in 2009 at all the 14 air pollution monitoring stations in Hong Kong. Note, the roadside stations in Central, Causeway Bay and Mong Kok have the highest concentration of NO_2 (112 µg/m^3) that greatly exceed Air Quality Objectives (AQO) limit of NO_2 (80 µg/m^3) (EPD, 2009, p. 4).

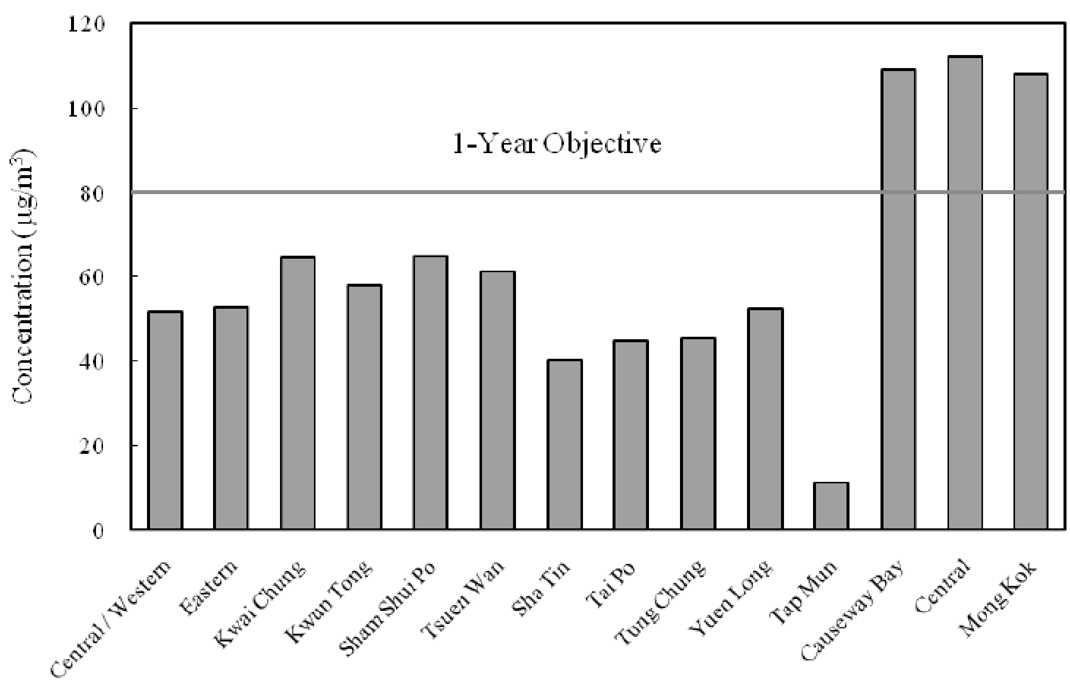

Figure 2-5: Annual average of NO_2 of 2009 (Environmental Protection, 2009)

Sulfur Dioxide

Sulfur dioxide (SO_2) is a result of the sulfur element being present in fossil fuels. Sulfur dioxide mostly affects the upper airways by stimulating bronchial constriction and mucus secretion. Asthmatics are especially vulnerable to sulfur dioxide. When deposited, most of the SO_2 dissolves in the airway and lung fluids as sulfites and sulfuric acid. These are irritating to the mucous membranes and promote irritation responses to ozone. Furthermore, sulfites and sulfuric acid inhibit upward mucous ciliary transport of pollutants, such as soot. Sulfites are then taken up in the blood and distributed throughout the body. (Feger & Tjell, 2009, p. 339)

An intervention study in Hong Kong of sulfur reduction in the composition of fuel oil in 1995 led to a remarkable drop of sulfur dioxide concentration from 44 to 21 $\mu m/m^3$, which was parallel with the annual death rate for respiratory diseases falling by 3.9% and for cardiovascular diseases by 2%. (Hester & Harrison, 2009, p. 119)

As is indicated in Figure 2-6, Kwai Chung had the highest value of SO_2 at 21 $\mu g/m^3$ in 2009. It can also be noticed that the study of sulfur dioxide reduction did work since SO_2 concentrations are moderately low in all of the areas of Hong Kong (EPD, 2009, p. 3).

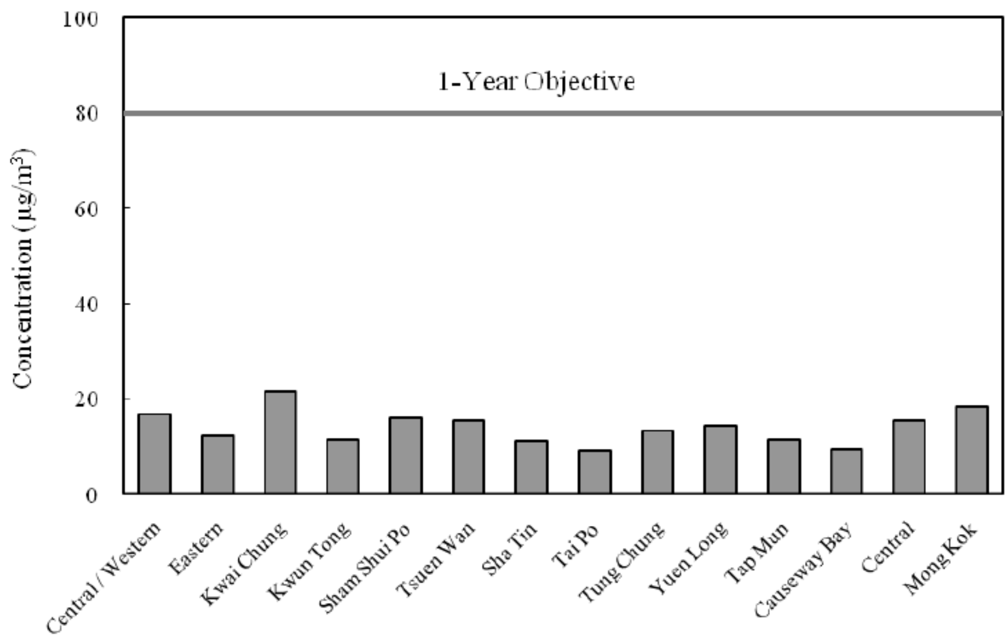

Figure 2-6: Annual average of SO_2 of 2009
(Environmental Protection, 2009)

Photochemical Oxidant (Ozone)

Strong sunlight, heavy traffic and the production of reactive organic species leads to the formation of ozone (O_3), a potent reactive and oxidizing gas. It is worth noting that ozone does not get emitted directly from man-made sources, but instead is a byproduct of reaction of nitrogen oxides (NO_x) and volatile organic compounds (VOCs). Ozone concentrations are the highest during the afternoon because its formation directly depends on the sunlight and traffic-generated precursors (Fenger & Tjell, 2009, p. 340).

Ozone has a direct negative effect on the respiratory system of the person. It has been noted that both daily deaths and admissions to the hospital are associated with the concentration of ozone in the air. People growing up in high ozone areas tend to have slow lung development, as well as reductions in indices of lung function and an increase in markers of inflammation in airway fluid sampled by bronchoalveolar lavage (Hester & Harrison, 2009, p. 122).

Particulate Matter

Particulate matter is another major urban air pollutant. It consists of soot, a solid fraction, and SOF (Solid Organic Fraction) an organic fraction (Fenger & Tjell, 2009, p. 132). Particulate matter contains water and volatile inorganic matter, like sulfur oxides. However, depending on the location, composition of this air pollutant varies greatly. For example, in the coastal areas sodium chloride is its major component, while in the areas next to coal or oil burning power stations it is ammonium sulfate. In the roads of urban areas, primary particles formed as organic components from vehicle engine exhaust condensation are predominant. Metals such as vanadium and nickel are also present in the composition of particulate matter.

There is a complex form of a particulate matter compound called polycyclic aromatic hydrocarbon (PAH), which is highly toxic and can cause chronic diseases. After getting inside of lungs, particles can irritate and harm the cells of the respiratory system because of their intrinsic toxic effects. They can be transported to other parts of the body by blood.

Depending on their form and size, the particles are divided into three main groups: PM_{10} (TSP), $PM_{2.5}$ (RSP), and $PM_{0.1}$ (Ultrafine), the subscripts mean that the particles are smaller than 10, 2.5, 0.1 µm respectively (Fenger & Tjell, 2009, p. 340).

Total Suspended Particulates (TSP)

TSP particles are those that have a diameter of less than 100 micrometers. When inhaled, they mostly become trapped in the upper airways, because their size prevents them from getting deeper into the respiratory system. In Hong Kong, the highest annual average (98 $\mu g/m^3$) of TSP was recorded at a Mong Kok roadside station in 2009 (see Figure 2-7) (EPD, 2009, p.8).

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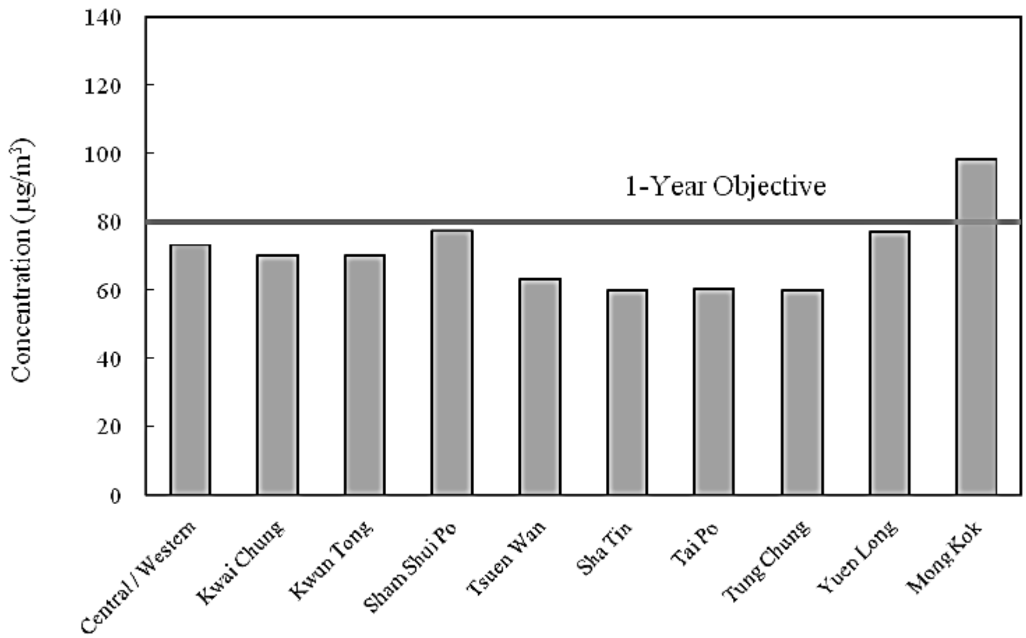

Figure 2-7: Annual average of TSP of 2009
(Environmental Protection, 2009)

Respirable Suspended Particulate (RSP)

RSP particles have a diameter of 10 micrometers or less. They enter peripheral parts of lungs and get transported to other organs by blood. According to the 14 general and roadside monitoring stations, the concentration of RSP is very high in all parts of Hong Kong, but the highest annual average was recorded in Causeway Bay (71 $\mu g/m^3$) (see Figure 2-8). Once again, the same three areas (Causeway Bay, Central and Mong Kok) all exceed Hong Kong's Air Quality Objective (AQO) limit of RSP (EPD, 2009, p. 9).

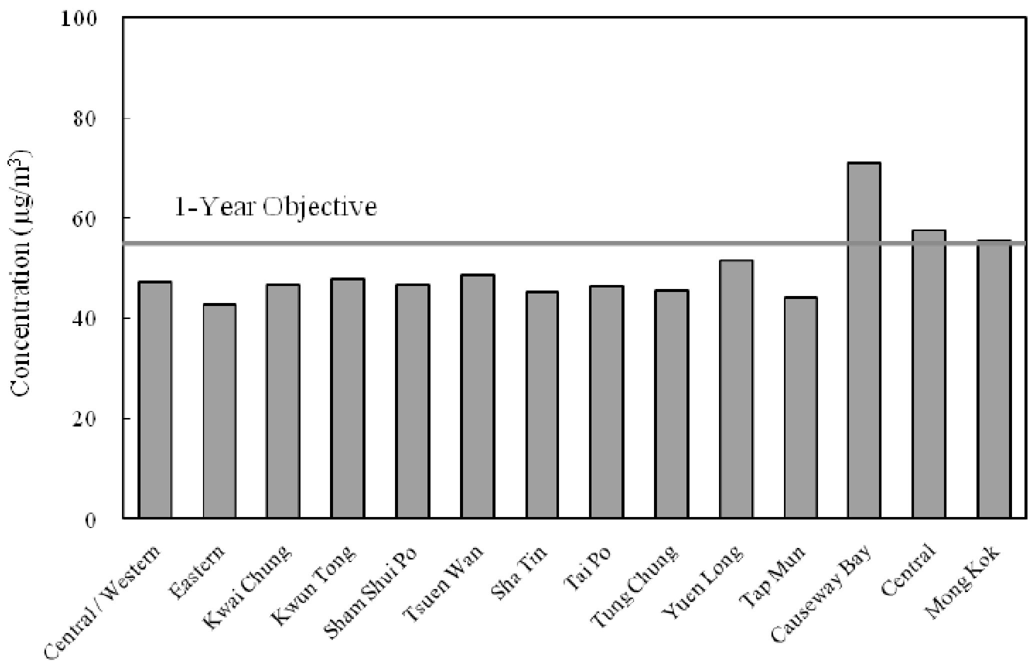

Figure 2-8: Annual Average of RSP of 2009
(Environmental Protection, 2009)

Ultrafine particles

Ultrafine particles are of a size of less than 2.5 nanometers (0.0025 μm), and can get to the gas-exchange part of the lung, where the clearance of particles is slower than from the conducting upper airways (Fenger & Thell, p. 340).

Carbon Monoxide

Carbon Monoxide (CO) is a toxic odorless gas that is primarily formed by incomplete combustion reaction of fossil fuels, as well as from vehicular emissions. Gasoline engines are the major contributors of carbon monoxide since the oxygen supply is insufficient in CO's formation. If oxygen levels are high, carbon monoxide gets oxidized into carbon dioxide (CO_2). Toxic effects of carbon monoxide can inflict significant damage on organs like the heart and brain. Carbon monoxide strongly binds to hemoglobin when entering the blood, which reduces the transport of oxygen into the cells of the organism. People with heart diseases are at special risk if exposed to carbon monoxide (Griffin, 2007, p. 27). Carbon Monoxide was monitored at four general and three roadside stations in Hong Kong continuously in the year of 2009. The highest 1-hour average of 5520 µg/m^3 was recorded in Causeway Bay (see Figure 2-9) (EPD, 2009, p. 6).

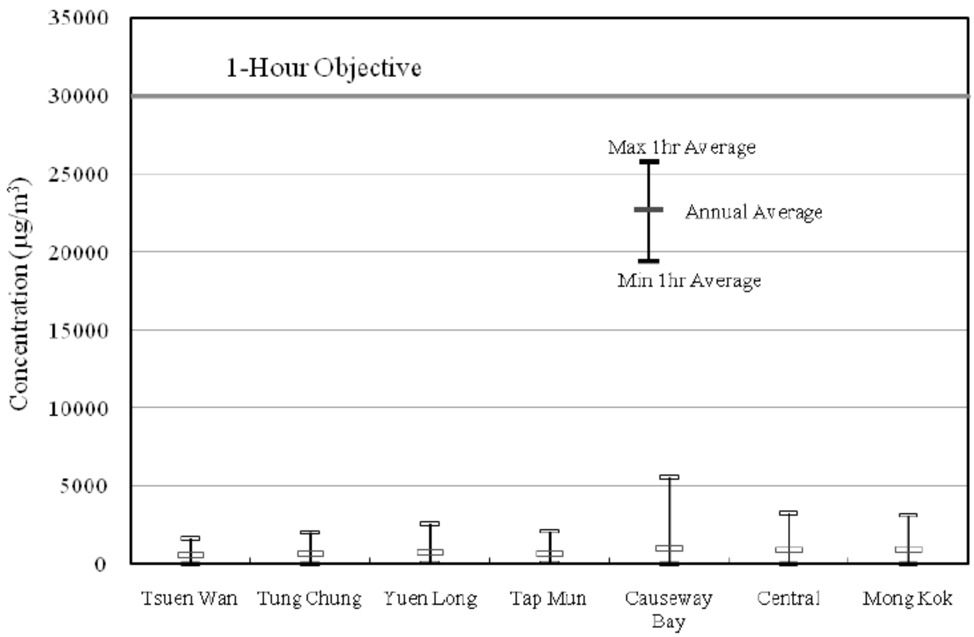

Figure 2-9: One-hour average of CO emissions of 2009
(Environmental Protection, 2009)

2.5. Effects of Air Pollution

Air pollution has a variety of negative effects on local life and societies. Depending on the severity of the pollution, a region may suffer greatly due to low air quality.

2.5.1. Biological Effects

Negative effects of air pollution on ecosystems have been known for many decades. For example, in the mid-1940s, agricultural crops in Los Angeles were lost because of phytotoxic air pollutants such as O_3. Since these discoveries, scientists started paying closer attention to the damaging effects of particular air pollutants such as ozone, sulfur dioxide, fluorides, nitrogen dioxide etc. on vegetation (Griffin, 2007, p. 37).

The effects of air pollution on plants depend on various physical and biological factors. Plant structure consists of four organs: roots, stems, leaves, and reproductive structures. In plants, the principal target for damage of the plant is leaf since it is responsible for the gas exchange process. Air pollutants enter the cell through the leaves and react with the tissues of the leaf, causing damage (Fenger & Thell, 2009, p. 363-364). Humans, too, suffer significantly from the effects of air pollution.

2.5.2. Health Effects

For centuries, various symptoms such as odor, eye irritation, and coughing that are caused by air pollution have been described throughout the globe. During the past ten years, research on health effects of air pollution has developed rapidly. Scientists have not necessarily been discovering new air pollutants, but rather have become much more knowledgeable of the effects and mechanisms of the air pollutants. Such progress has occurred due to the large number of studies reported, advancement in epidemiological methods and also developments in meta-analytical techniques.

Health effects related to the air pollution can be categorized into two groups: acute and chronic. Acute health effects are immediate responses by the body resulting from an immediate contact of eyes and lungs with the ambient air. Some examples of the acute health effects of air pollution are burns and asphyxiation. Chronic health effects are those which are dependent on the amount of exposure and the time period between the initial exposure and the impact to the individual’s health (Griffin, 2007, p. 21-22).

Smog is one of the most dangerous air pollution indicators. In developing countries, smog is still a frequently occurring incident. There has been a parallel line drawn between air quality and morbidity/mortality rates throughout the past decades. It is reflected through a sudden increase in use of medicine, absence at work, doctor appointments especially for people with chronic heart and lung diseases and finally registries of mortality.

2.5.3. Reduction of Visibility

Visibility is considered to be a good indicator of air pollution levels (Civic Exchange, 2006). The way people see a distant object is more connected to its contrast to the background than the luminosity of the surrounding area. The contrast between an object and the background gets reduced whenever the light passes through the air and continues to be reduced depending on the level of air pollution. Light absorption and scattering are primary factors in visibility reduction. These processes can be caused by gases and particles.

Gases, such as nitrogen dioxide, tend to absorb shorter blue wavelengths which lead to a more distinct red radiation. Higher concentration of nitrogen dioxide in the air makes it appear to be reddish-brown. Scattering by gaseous molecules reduces the contrast of an observed object. Nitrogen dioxide concentration of 100-500 $\mu g/m^3$ can reduce the visibility from 300 km which is the visibility in pure air to 100 km in polluted air.

Suspended particles like aerosols are the major contributors of visibility reduction due to air pollution. In fact, aerosols make up 80% of total contribution, especially particles with a diameter of 0.1 – 1 µm. Humidity also plays a large role in the effects of particles on visibility (Fenger & Thell, 2009, p. 359-361).

2.5.4. Economic Effects

Besides the fact that poor air quality significantly affects public health, it is very important to note that air pollution negatively affects international reputation and tourism of the country as well. International companies all over the world have been using Hong Kong as a gateway to the mainland Chinese market. However, severe air pollution has been affecting the international reputation of Hong Kong. There are numerous international business companies in Hong Kong. For example 1,400 U.S. companies are located in Hong Kong and more than 60,000 Americans are currently living and working in the area.

Experts in the public health field have calculated different economic and financial costs caused by illness, hospitalization, lost workdays, and mortality caused by air pollution. Reducing air pollution in Hong Kong would save 1,600 lives and 64,000 hospital bed days, which could save over HK $21 billion annually (Civic Exchange, 2008). For example, according to Civic Exchange's 2006 annual report, direct health costs and productivity losses of HK$2 billion as well as intangible costs of pain and suffering of HK$19.2 billion can be reduced by improving the air quality in Hong Kong.

According to the latest quality-of-living survey from Mercer, a U.S. – based consulting firm, Hong Kong ranks 71st in the world in quality of life. For comparison, Singapore, another successful Asian port city-state, is 28th in that same survey. Another important indicator of the air pollution severity in Hong Kong is the fact that 40% of member companies have been having difficulties in recruiting people to work in the city. According to Civic Exchange's public opinion survey, 25% of the total population is considering leaving Hong Kong because of air pollution, the percentage increased by 5% over a short interval of two years. Moreover, 50% of

Hong Kong residents with postgraduate degrees are considering leaving due to the poor air quality (2010, p. 1).

From all the air pollution effects mentioned above it is obvious that improving the air quality in Hong Kong should be a priority. Once the severity of the situation has been realized individuals and organizations should pressure the government into taking more definitive action. The government's help in changing the regulations and policies is needed to address the problem of roadside air pollution and its environmental justice problems.

2.5.5. Air pollution as a Social Issue

Throughout the world, there are issues that affect the residents of an area or region unequally. These inequalities are known as environmental justice issues. According to the Environmental Protection Agency, environmental justice is defined as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (Environmental Protection Agency, 2010, para. 1). Air pollution is an environmental justice issue. Environmental justice revolves around the concept that environmental issues such as air pollution do not affect everyone at the same level. The impact of the air pollution on different social classes enables the study of air pollution from an environmental justice viewpoint.

The level of an individual's exposure to air pollution in Hong Kong is directly related to his or her work place. Outdoor workers such as vendors and construction workers are the most vulnerable group of people since they are exposed to roadside air pollution much more than people working indoors. Regularly breathing polluted air has its negative consequences on the health of outdoor workers (Stern, 2003, p.789). For example, thirty percent of outdoor workers suffer from illnesses caused by poor air quality such as asthma, throat irritation, and eye/nasal allergies. Another group of people who is harmed by air pollution are taxi, minibus and bus drivers, since the highest levels of air pollution are located inside of the polluting vehicles.

In 2000, there was a study comparing four Hong Kong hospitals. Two hospitals, United Christian Hospital and Caritas Medical Centre, were located in the lowest-income districts while the other two hospitals, Queen Mary Hospital and Tung Wah Hospital, were located in the highest-income district. Taking the number of beds in these hospitals into the consideration; Queen Mary and Tung Wah Hospitals had a total of 2,109 beds, and United Christian Hospital and Caritas Medical Centre had a total of 2,437 beds. Data on number of cases of Acute Upper Respiratory Infection (AURI), acute bronchiolitis, and chronic/unspecified bronchitis were collected in all hospitals. These afflictions were chosen due to the fact that respiratory illnesses are mostly caused by the air pollution, roadside pollution in particular. As shown in Table 2-2 below, the two hospitals in the low-income areas have much higher numbers for the duration of stay of patients with Respiratory Illnesses. This indicates that people in low-income areas are more likely to be hospitalized for respiratory illness than people from high-income areas (Stern, 2003, p.790).

Hospital	# of Beds	# of Bed Days/Year	Total Length of Stay for Respiratory Illnesses (Combined for All Respiratory Illnesses)	% of Beds Occupied by Patients with Respiratory Illness
Queen Mary Hospital (Pokfulam, high income)	1,400	511,000	4,940	0.97%
Tung Wah Hospital (Sheung Wan, high income)	707	258,055	288	0.1%
United Christian Hospital (Kwun Tong, low income)	1,265	461,725	14,791	3.2%
Caritas Medical Centre (Shamshuipo, low income)	1,172	427,780	8,395	1.96%

Table 2-2: Rates of respiratory illness and income differentials
(Stern, 2003, p.790)

2.6. Hong Kong Government

Hong Kong's air quality policies are drafted and implemented by the local government. Two governmental departments are of significant importance when considering the issue of roadside air quality in Hong Kong: the Legislative Council and the Environmental Protection Department.

2.6.1. Legislative Council

The main legislative body of Hong Kong is the Legislative Council (LegCo). Made up of 60 members, the LegCo is responsible for proposing, voting on, and passing legislation for the territory (HK Basic Law anx. II, art. II). While 30 members of the LegCo are democratically elected according to geographic constituencies, the other 30 members serve functional constituencies. Functional constituencies are major sectors of Hong Kong's society and economy deemed to have sufficient importance to merit their own representatives. Functional constituencies, representing several areas relevant to the air quality of Hong Kong, include transport, tourism, social welfare, and architectural planning and development. Hong Kong's Basic Law does not specify how representatives of functional constituencies are elected or appointed.

Having a vote in one functional constituency does not preclude having a vote in a geographic, or even another functional constituency. As a result, certain people, as well as corporations, have the power to elect multiple representatives in Legislative Council elections. This gives an entity in a functional constituency more votes than a typical individual in Hong Kong. Consequently, certain entities play a much greater role than others in determining the air quality policies of the government of Hong Kong.

Additionally, the votes required to pass a bill differ depending on the entity which proposes the bill. Thus, it only takes a simple majority of LegCo members present to approve a bill proposed by the government. Bills proposed by individuals within the Legislative Council, however, require a majority among geographic constituency representatives as well as a majority among functional constituency representatives (HK Basic Law anx. II, art. II). The result is a system which weighs the interests of the voting citizens of Hong Kong and the special interest groups of Hong Kong in equal measure. Thus, the latter group is effectively as powerful in the legislature as the voting citizenry, and has considerable influence over bills proposed, such as those drafted by the Environmental Protection Department.

2.6.2. Environmental Protection Department

The Environmental Protection Department (EPD) is the primary government department dealing with environmental matters in Hong Kong. In a general sense, the EPD crafts environmental policies, monitors pollution and environmental degradation, and acts in an advisory capacity for other entities. The Air Programme is the department of the EPD which deals with air pollution through a combination of policy drafting, implementation, and enforcement. It also monitors air pollution through the use of 14 monitoring stations across the territory.

EPD air monitoring stations fall into two types. The first of these is the "general" station. There are 11 general stations situated in Hong Kong. General stations lie between 11 and 25 meters above the ground and are in a diverse range of terrain types from densely urban to rural and largely undeveloped. The second type of station is the "roadside" station (EPD, 2011). Only three roadside monitoring stations exist in Hong Kong situated between 3 and 4.5 meters above the ground. The stations are located in Causeway Bay, Central, and Mong Kok, all of which are highly urbanized and dense areas. The EPD then uses data from all of these sensors to generate the Air Pollution Index (API) which serves as a measure of the degree of air pollution in Hong Kong. According to the EPD, for API values from 0-100, which range from low to high, they do not recommend any action be taken. For API values from 101-200, classified as very high, persons with respiratory and heart conditions may be adversely affected. Above 200, all persons may be adversely affected (EPD, 2010a).

2.6.3. Air Policy Results

Following the handover of Hong Kong to China, the government voiced stronger concerns and pledges to prioritize improving the air and reducing vehicular emissions. The official goals in 1999 were to tighten emissions standards for vehicles, offer cleaner alternatives to diesel and technologies to trap pollutants from diesel, strengthen inspection stringency and frequency, and promote better vehicle maintenance. This set of official objectives followed a

1995 law to reduce the sulfur content permissible in diesel fuel, which considerably reduced SO_2 levels in Hong Kong (Trumbull, 2007, p. 35),

One of the strategies the government has adopted is a combination of tax and other financial incentives to lower vehicle emissions. A key example of this is the program to convert taxis in Hong Kong from diesel fuel to liquefied petroleum gas (LPG). By lowering the import duty on LPG and paying taxi drivers to turn in their diesel cars, as was described earlier, the government was able to facilitate the conversion of all taxis in Hong Kong to LPG. This was paired with other, compulsory policies, including the 2001 ban on imports of and 2006 ban on operation of diesel-fueled taxis. The program to convert light buses to LPG, another example of stimulating economic incentive to modernize vehicles, has been widely successful as well.

For heavy buses, the primary focus of the government has been to modify routes to reduce traffic congestion and move former bus users to rail. Many bus routes have been changed, reduced, or eliminated in the past decade under these programs. In Central, for example, 1,917 bus trips have been eliminated by rationalizing the routes taken, with similar results for other parts of Hong Kong (see Figure 2-10). However, bus route modification has not progressed much for Central in recent years; between 2008 and 2009, only one bus trip was eliminated (Hong Kong Transport Department, 2009, p. 5).

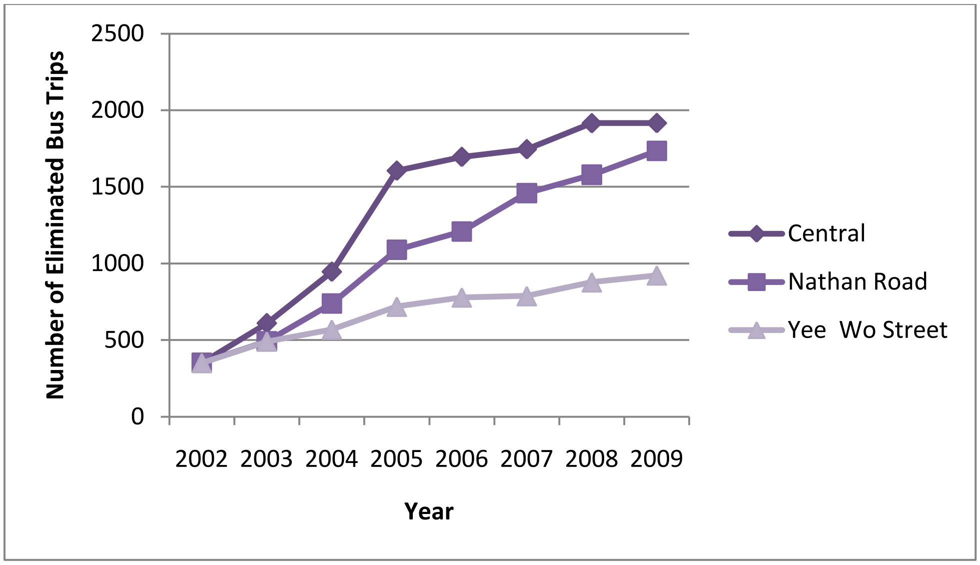

Figure 2-10: Cumulative number of bus trips eliminated in Hong Kong, 2002-2009 (Hong Kong Transport Department, 2009)

Air pollution policy in Hong Kong has resulted in some improvement in vehicular, roadside levels. Between 1995 and 2005, official estimates of RSP and SO2 emissions declined by 80% and 91%, respectively, due to vehicle modernization efforts and restrictions on sulfur content permissible in fuel. However, despite these examples of success, Hong Kong's air policy has not led to cleaner air overall. Large discrepancies exist between these official estimates of pollutant declines and low air quality, particularly at the roadside, and not all pollutant levels have been reduced as drastically as RSP and SO2.

One major factor in the high roadside air pollution is the failure of many buses in Hong Kong to adhere to modern emissions standards, such as the European Union's (EU) emissions standards, Euro I-V. As of 2006, new engines must adhere to Euro IV standards, but the government allows pre-Euro and Euro I engines, which emit 30 times more NOx than Euro IV engines, to stay on the road (Trumbull, 2007, p. 52-53). Because there are no mandatory pull-out programs for buses, the bus companies themselves have little economic incentive to move to buses that are less harmful to the environment. Many pre-Euro and Euro-I buses are on the roads of Hong Kong today and have a disproportionately high impact on local roadside pollution from vehicles. By one particular estimate, as much as 70% of pollution from buses may be attributed to the 12% of buses which are pre-Euro and Euro I (Trumbull, 2007, p. 53). This problem is only exacerbated by mounting difficulties in expanding the rail network of Hong Kong.

It is the government's official goal to prioritize rail transit over road transit (Trumbull, 2007, p. 51). This is problematic, as the government does not actually subsidize the rail system directly, thus requiring stations to be profitable and the rail network to be self-sustaining. There is little motivation, then, to build MTR stations in areas that will not provide a strong return on investment.

While vehicles do play a large part, they are not the only sources of air pollution in the territory. Rising pollution from sources other than motor vehicles, such as marine vessels and manufacturing in the mainland, is at least partly responsible. Shipping is a vital component of the economy of Hong Kong, and the large number of container vessels with dirty fuels negatively impacts the air quality. Air pollution from the mainland also blows towards Hong Kong, further degrading the air (Trumbull, 2007).

2.6.4. Results from Other Cities

Many recommendations have been made regarding improving the air quality of Hong Kong in general, as well as reducing roadside pollution from vehicular sources. For the buses, Trumbull (2007) recommends government subsidies of rail programs and mandatory pull-out programs for pre-Euro and Euro I buses. Low duties on certain fossil fuels, too, lead to a lack of incentive to switch to less environmentally harmful fuel sources (p. 55). Hong Kong is far from the first city to suffer the effects of roadside air pollution, however; other cities have dealt with the same issues. In particular, Singapore and New York City have been chosen for comparison with Hong Kong.

Singapore

Singapore, a major city-state in South Asia, was chosen on the basis of its status as both a large city and a significant Asian port. Like Hong Kong, Singapore has an extensive public transit network serving its territory, including a large bus fleet. According to the Singapore Ministry of the Environment, Water, and Resources (MEWR), all diesel vehicles in Singapore imported or produced following October 2006 are required to comply by Euro IV fuel standards (MEWR, 2010), a situation comparable to that of Hong Kong. However, Singapore's air is significantly cleaner than that of Hong Kong.

Singapore's Pollution Standards Index (PSI) and Hong Kong's Air Pollution Index (API) are fairly similar at the 51-100 point range, considered “medium” in the PSI and “high” in the API. By these metrics, approximately 6% of Singapore’s days in 2010 were ranked as medium or higher on the PSI (National Environment Agency, 2010). This is a significantly lower portion than Hong Kong, which counted approximately 90% of its days at the roadside as high or higher on the API (EPD, 2010c). The Hong Kong EPD reports roadside air pollution differently from non-roadside air pollution, however, while the Singapore NEA reports only one air pollution metric.

To regulate air pollution in Singapore, particularly at the roadside, it uses a combination of pollution regulation and traffic control policies. In particular, the city-state has implemented a unique toll system and strict vehicle permit issuance program to control the number of cars on the road (Ministry of Transport, 2010). The toll system, known as Electronic Road Pricing (ERP), charges drivers a fee to enter and use high-traffic roads. The result is a low number of vehicles on the road at any given time, which is quite different from the frequent traffic jams which Hong Kong faces.

The Hong Kong government has considered the possibility of implementing ERP in the territory by conducting a feasibility study in 2001. Despite conclusions illustrating that the system could be feasible and effective in moving more people to public transit, the system was never implemented (Transportation Department, 2001). No further studies were conducted subsequently, and to this day Hong Kong is without an ERP system.

New York City

New York City provides an apt comparison to Hong Kong due to its high population and public transport utilization. Like Hong Kong, the city has significant pollution issues, particularly in poor neighborhoods. US census data from 2000 indicate that asthma risk is higher than average in economically deprived areas of New York City. The city also has elevated levels of ozone and other pollutants due to a denser population and high buildings (Coburn, Osleeb, and Porter, 2006). These problems are much less severe than those of Hong Kong due at least in part to proactive transport and air pollution policies.

New York's public transit system is largely run by the Metropolitan Transportation Authority (MTA), which is publicly chartered and subsidized by the city. MTA-run buses account for approximately 80% of all ground transit in New York (MTA, 2010). According to the Institute of Electrical and Electronics Engineers (2010), or IEEE, concerns about modernizing buses have led to an extensive conversion to hybrid buses. As of April 2010, the city was well on its way to achieving its goal of deploying 1,675 hybrid buses by July of that same year. The buses themselves emit far lower levels of particulate matter and nitrogen oxides (p. 1).

The main differences between Hong Kong's and New York's public transportation systems are the degree of subsidies and modernization efforts. Hong Kong's bus fleet is essentially privately-run, and thus most modernization efforts come from the private sector. The government does implement regulations such as the Euro IV standards, but in general the companies are under less influence than the MTA, which is chartered by the New York City government (MTA, 2011). Modernization efforts are far more extensive in the MTA than the private bus companies of Hong Kong. The New York City government was in possession of nearly 1,700 hybrid buses as of 2010; Hong Kong transportation is essentially devoid of hybrid buses. Furthermore, as of 2009, 99.1% of the 5,627 franchised buses in the territory were pre-Euro IV (Clean Air Network, 2009). Thus, only approximately 50 buses complied with Euro IV or higher standards. This illustrates a wide gap in the vehicle modernization policies of the two governments.

3. Methodology

Understanding the impact of buses on roadside air pollution, as well as the impact of the pollution on the disadvantaged people of Hong Kong, is a complex process requiring many types of expertise and data analysis. Achieving the goals of the project required a combination of interviews with scholars and experts, as well as extensive analysis of vehicular, population, and pollution data. This chapter describes the methods employed to gather and analyze information and data.

3.1. Interviews

Interviews were the main method by which the team gathered preliminary research information. Scholars and experts in the field of air pollution research were determined to be the most reliable sources of information for analysis in the early stages of the project. Interview subjects were selected on the basis of their research domain and expertise, as well as relevant published material. In total, 11 individuals or organizations were contacted with interview requests (see Appendix A). The project team conducted interviews with four research teams led by: Professor WT Hung of Hong Kong Polytechnic University, specializing in transport; Mr. Mike Kilburn of Civic Exchange, specializing in environmental policy and affairs; Professor Chak Chan of the Hong Kong University of Science and Technology, specializing in air pollution; and Professor Sarah McGhee of the University of Hong Kong, specializing in public health economics.

3.1.1. Contact Protocols

The process of contacting and scheduling interviews followed two phases. The first of these was initial contact via email. An email protocol was drafted (see Appendix B) explaining the purpose and scope of the project. The general format was the same between each message, though with some flexibility in tailoring email messages to suit the individuals. Recipients typically responded with tentative scheduled availability which the project team then used to confirm an appointment by email.

Generally, sending requests via email provided favorable response rates. Of the 11 people and organizations contacted, the team received 8 replies. Four respondents indicated availability which led to appointment confirmations, three respondents indicated tentative availability with no further contact from the respondents following these replies, and one individual declined to be interviewed.

The second phase of the contact process required the use of telephone calls as the primary means of communication. After the initial emails had been sent, the project team made follow-up phone calls to those potential interview subjects who did not respond electronically. As with the email protocol, a scripted call protocol was drafted (see Appendix B) to explain the project. These follow-up phone calls were unsuccessful. Messages were left with the secretaries of two interview subjects, and one was left directly on another interview subject's voicemail. The team received no further response from these individuals.

3.1.2. Interview Protocol

Each interview followed a semi-structured interview protocol, with a set of questions for all interview subjects (see Appendix C). Flexibility was allowed for additional questions for individual subjects to gain more information regarding his or her domain of expertise. Two group members were designated to speak with the interviewee for each interview; the other two group members took detailed notes. These roles were not, however, strictly enforced. The group wanted to ensure that any questions that might arise would be asked, even if the person who asks a question was not the designated interviewer.

Initially, the team anticipated that the interviewees would be asked all the questions from the protocol and in the order listed. Due to the different settings and structures of each interview, however, questions from the interview protocol were asked as needed in a more natural order. Not all protocol questions were used in all interviews, either due to subjects providing relevant answers on their own or the questions themselves falling outside of the expertise of certain subjects.

Interviews were generally very successful in gaining both research material and further contacts. While the original plan was to directly cite the interview notes in the project results, most of the statements from interview subjects were in their published materials. Often, subjects would provide either the titles of these materials or the documents themselves. Thus, the interviews were primarily used to gather data which were then supplemented with other sources.

Interview with Professor WT Hung at Hong Kong Polytechnic

This was the first interview the team had conducted in Hong Kong, and at the time the team was expecting a structured interview that would follow the interview protocol. Instead, after letting the team introduce the scope of our project, Professor WT Hung explained Hong Kong's bus system as well as his opinion on the necessity of improving it.

Professor Hung stated that all buses in Hong Kong are owned and operated by private sectors. Franchised buses specifically are regulated by the Transport Department. Looking at the total length of all roads combined which is less than 2000 km, Hong Kong is very small. Most of the bus routes are overlapping in one section, such as Central, which has very high traffic congestion. Regarding bus companies upgrading their buses, Professor Hung mentioned that The Kowloon Motor Bus (KMB) has upgraded some of the buses, while New World First Bus and Citybus have not upgraded any. The Hong Kong government puts billions of dollars to subsidize vehicle owners, but none to subsidize buses. Last month, bus companies asked for 13 new hybrid buses that have a total cost of 13 million HKD for testing, and which will not necessarily be used by public by the end of the tests. Currently the market share between buses and the MTR are about 50/50. However, the government has a plan of increasing MTR market share up to 60% by 2030.

Interview with Mr. Mike Kilburn at Civic Exchange

The interview with Mike Kilburn was the most structured interview we had, since it followed our interview protocol. We used the specific set of questions which were all precisely answered.

In Mike Kilburn's opinion air pollution is a topic of great social importance. Because the local government has no intentions of doing anything serious to remedy the situation, the air quality of Hong Kong has not been improving. He agrees with the fact that the most affected group of people in Hong Kong are drivers, newsstand workers, open door shopkeepers, people at ports etc. During the interview, the Hedley Index was mentioned. This index is an alternative air pollution index calculated on the World Health Organization's (WHO) air pollution guidelines as opposed to Hong Kong's Air Quality Objectives (AQO). The team was shown level of nitrogen oxides and graphs that compare roadside emission levels. The Kowloon Motor Bus (KMB) prefers not to retire the old buses, letting them run on the roads for the extra 18th year, which is when the buses may emit the most pollutants in the air. In order to upgrade/update any bus the company has to get special permission from the government and there is no public input involved. Mike Kilburn also noted that the routes of the buses are not planned correctly because many of them overlap.

Interview with Professor Chak Chan and Dr. NT Lau at Civic Exchange

This interview also had a different approach, since Professor Chak Chan and Dr. NT Lau had a PowerPoint presentation about the Mobile Air-monitoring Platform (MAP) used for monitoring air pollution. They introduced the concept of MAP being able to measure pollution levels and location simultaneously. The sensors were placed 3.5 meters above the ground to measure the street-level pollution. While 3.5 meters above the ground is still above the height of the individuals who are affect by the pollution, at this height there ceases to be spikes in pollution readings from vehicles and machinery operating at the roadside. At this height, the pollution is monitored consistently.

MAP was also used to measure pollution levels in tunnels, which was challenging due to private ownership of tunnels and the size of the sensors. Pollutant levels varied depending on the direction MAP used to enter the tunnel. For example, coming from North to South, there were higher levels of sulfur dioxide (SO_2) since the vehicle was coming from mainland China. It was also noted that pollution accumulates with distance from entrance. The MAP study demonstrated that higher levels of pollution are directly associated with high bus traffic (Lau, Yeung, Lau, Chan, 2010).

Interview with Professor AJ Hedley, Professor SM McGhee, Dr. CM Wong, and Dr. HK Lai

This interview was the most formal interview the team had. Initially, the interview followed the interview protocol, but the second part was less formal and was more of a group discussion. Professor SM McGhee noted that new buses tend to be on longer routes, while the older buses are on shorter routes (poor areas). Professor AJ Hedley mentioned the fact that given the traffic congestion buses, create a microenvironment, an environment within a small area. Professor AJ Hedley also noted that the government has a system of defining small units of land, “Tertiary Planning Units” (TPU), which are the smallest units of land the Census and Statistics Department uses. Hong Kong has, according to the experts in attendance, some of the most roadside polluted areas in the world, specifically regarding NO_x. Hong Kong’s food gets imported from mainland China using trucks with cheap, dirty, Chinese diesel.

It was noted that other sources of pollution exist at the roadside besides vehicles, including construction projects which the government has started to develop more roads and bridges. According to the interviewees, this roadside construction is a significant source of concern as their construction will result in both short-term and long-term damage to local air quality due to their contribution to air pollution. Another concern mentioned was lax Air Quality Objectives (AQOs) instated by the government.

3.2. Literature Review

A significant proportion of the data used in the project was gathered through scientific literature. Using the interviews and other preliminary research as a starting point, a literature review was conducted. The review encompassed data regarding the impact of buses on roadside air pollution in Hong Kong and the effects of the pollution on the disadvantaged population. Much of the literature was used in conjunction with the results of interviews to produce the project outcomes. Data were collected on a document-by-document basis for further analysis. In particular, extensive transport, pollution, and population data were collected and analyzed.

3.3. Data Analysis

In order to provide a firm quantitative foundation on which to base conclusions, it was necessary to gather and analyze quantitative data through research to produce a clearer picture of the impacts of buses on both overall pollution and public health. There were three types of data used from different sources: vehicular and traffic data from the Transport Department and Clean

Air Network, roadside pollution data from the Civic Exchange, Hong Kong University of Science and Technology, Mobile real-time Air monitoring Platform (MAP), and population by-census report data from the Census and Statistics Department.

The population data were organized by district and Tertiary Planning Unit (TPU), the smallest geographic unit in the by-census report. MAP data were organized geographically by District Council district, with each district matching to a dataset. These data did not encompass all roads within districts, but rather routes which were deemed representative of overall air pollution in the districts. Supplementary data were provided for selected main roads as well.

Due to time constraints, an in-depth analysis of all districts of Hong Kong was not feasible. Instead, the group chose six locations, three urban areas and three highways, as a representative sample of locations most severely affected by roadside pollution. The three urban areas were: Yau Tsim Mong, Central/Western, and Wan Chai. These districts contain Nathan Road, Des Voeux Road, and Hennessy Road, respectively, which MAP data show are the most polluted main roads in Hong Kong. The three highways sampled were: Tsing Kwai Highway, San Tin Highway, and Tolo Highway. These highways were chosen because they are the most polluted out of all the highways in Hong Kong.

3.3.1. Vehicular Analysis

The first phase of data analysis used vehicular data to determine the contribution of buses to roadside air pollution in Hong Kong. Statistics from the Transport Department and Clean Air Network were used to estimate the number of buses which are franchised relative to all buses in Hong Kong. These estimates and the contribution of these buses to roadside air pollution were compared to overall roadside air pollution generated by commercial diesel vehicles.

Initially, the team had planned to contact the major franchised bus companies of Hong Kong—Kowloon Motor Bus (KMB), Citybus, and New World First Bus—requesting data regarding bus routes and types of buses on each route. These data were then to be used to determine the number of franchised buses that traveled on Nathan Road, Hennessy Road, and Des Voeux Road, as well as the routes and types of buses on these roads. All attempts to contact bus companies were unsuccessful, and as a result these data were not available.

Due to time constraints and a lack of available data, the largest franchised bus company, Kowloon Motor Bus (KMB), was used as a case study. The team physically counted the number of bus stops on each of the aforementioned roads via the KMB website and computed the total length of each of these roads. The number of bus stops on each road was then divided by the total length of the road to estimate the average distance between bus stops.

3.3.2. Demographic Analysis

Determining the impact of roadside pollution on the people of Hong Kong requires an understanding of the demographics of people who live in the sampled, polluted districts. Data from the Census and Statistics Department's 2006 population by-census report (Census and Statistics Department, 2006) were used for analysis. In particular, the project team focused on statistics regarding population size, as preliminary research indicated these were related to levels of pollution in districts.

3.3.3. Pollution Analysis

Selecting three District Council districts, pollution levels were analyzed within the districts and along the major roads to determine the locations of the most polluted regions within the districts. In particular, the team reviewed MAP study data used to analyze the three most polluted roads in Hong Kong and their surrounding districts. Pollution concentrations were assessed along these roads to identify a difference, or lack thereof, between concentrations along major roads and in the three districts overall.

Pollution concentrations for the three urban roads were compared to pollution levels for three highways. These pollution levels were also compared with the Hong Kong Air Quality Objective (AQO) and the World Health Organization (WHO) guidelines. Additionally, traffic volumes for these same roads and highways were compared to find possible relationships between traffic volume and pollution concentrations.

3.3.4. Social Class Analysis

Air pollution in Hong Kong is an issue which may have a strong negative impact on the health and livelihoods of disadvantaged people. Investigating potential links between roadside pollution and social status required data from multiple sources. The team gathered pollution data from MAP studies through HKUST and Civic Exchange (Lau, Yeung, Lau, and Chan, 2010). Population data were acquired through the Hong Kong Census and Statistics Department by-census reports from 2001 and 2006 (Census and Statistics Department, 2001, 2006). All analyses were conducted using the three selected District Council districts—Central/Western, Wan Chai, and Yau Tsim Mong—for detailed study. These districts were studied as a single aggregate sample population. Studying the relationship between social class and roadside pollution levels required the use of data on a scale smaller than that of the whole districts. Data analysis was conducted at the Tertiary Planning Unit level.

A Tertiary Planning Unit (TPU) is the smallest geographic used in the Census and Statistics Department 2006 data set. TPUs vary in size and shape, and are classified under Seconday Planning Units (SPU). These SPUs follow the boundaries of established district areas in Hong Kong, such as Mong Kok and Yau Ma Tei, but not always the District Council district due to the aggregation of several districts into one District Council district. Additionally, certain SPUs are split between multiple District Council districts. For example, SPU 1.4 and all TPUs within 1.4 correspond to the mid-levels district, which is located in both Central/Western and Wan Chai. The TPU boundaries follow the District Council district boundaries where such a split exists. In total, 44 TPUs were studied.

For each Tertiary Planning Unit (TPU), the team computed a modified Social Deprivation Index (mSDI) value. This index incorporates five indicators of social status in its computation. These are the proportions of the population with: never being married status, no formal education, a single-person household, subtenancy (living as a tenant in another household), and income under $2000HKD ($250USD) per month. mSDI values are computed by taking the unweighted mean of these five factors. The range of the mSDI is 0 to 1, where 0 corresponds to no social deprivation and 1 corresponds to complete social deprivation.

An example calculation for the mSDI is as follows. To calculate the mSDI for any TPU, the following formula is used, where the number in brackets represents the percentage of the population in that particular category:

Equation 3-1: $mSDI = \frac{(never\ married)+(no\ education)+(single\ person\ home)+(subtenancy)+(low\ income)}{5}$

For an example TPU with a never-married population of 10%, an uneducated population of 12%, a single-person home population of 9%, a subtenant population of 8%, and a low-income population of 15%, the mSDI value would be 0.108. This value would be calculated as follows:

Equation 3-2: $mSDI = \frac{0.10+0.12+0.09+0.08+0.15}{5} = 0.108$

The mSDI is based on a Social Deprivation Index (SDI) from a previous study in 2008 (Wong et al., 2008) linking mortality from air pollution to low social status. The computation methods and factors used are the same between the mSDI and SDI, with the exception of unemployment data. The SDI takes unemployment into account as a sixth factor. The factor associated with unemployment information could not be included in calculating the mSDI due to a lack of available data separated by TPU. Both of these indexes are just some of multiple potential methods of quantifying social deprivation. The team chose the SDI as the model from which to design the mSDI on the basis of ease of computation, availability of the component data, and its use in other published materials.

mSDI values were calculated for each of the 44 TPU's based on 2006 by-census data. Appendix D contains all of these data in tabular form. Next, the mSDI values and TPUs corresponding to those values were sorted by mSDI and split into equally-sized tertiles by mSDI: high-mSDI, medium-mSDI, and low-mSDI. The low-mSDI tertile contains 14 TPUs, the medium-mSDI tertile contains 15 TPUs, and the high-mSDI tertile contains 15 TPUs.

For each mSDI tertile, the number of TPUs in the tertile containing a segment of either Nathan Road, Hennessy Road, or Des Voeux Road, as well as the number of those not containing a segment of one of these roads, was calculated. This was used to generate directly the frequency distribution of the presence or absence of these road segments by TPU in each mSDI tertile.

In the next step in the analysis, the percentage of TPUs containing a segment of one of these roads was calculated for each mSDI tertile by dividing the number of TPUs containing a road segment by the total number of TPUs in the tertile. For example, for an mSDI tertile containing 12 TPUs, 3 of which contained road segments with high levels of air pollution and 9 of which did not, the following calculations would be performed:

$$Percentage\ of\ TPUs\ containing\ road\ segments\ = \frac{3}{12} = 0.25$$

$$Percentage\ of\ TPUs\ not\ containing\ road\ segments\ = \frac{9}{12} = 0.75$$

The frequency distribution of the presence of these roads in each mSDI tertile was used to test whether mSDI values, and thus social deprivation, were related to the presence of any of these three roads with high levels of roadside air pollution in Tertiary Planning Units. Chi-square tests are a standard method of testing the goodness of fit of a frequency distribution of events to a given model, where the null hypothesis is that the observed data fit the expected model. The chi-square test compares the observed distribution with the expected distribution and produces a probability, also known as a p-value, that the observed data fit the expected distribution. If the p-value falls below a pre-determined alpha value, or threshold of statistical significance, the null hypothesis is rejected and the observed data are concluded to not fit the expected distribution.

In this case, the distribution of road segments among the TPUs in the three mSDI tertiles was tested using the Pearson's chi-square test. The null hypothesis was that the distribution of road segments was uniformly random across mSDI tertiles, with an alpha value of p=0.05. A rejection of the null hypothesis, then, would imply that the distribution of these road segments is unlikely to be uniformly random across all mSDI tertiles. The team then compared these results with previous studies of social class and air pollution to further understand the relationship between social class and roadside air pollution concentration and exposure in Hong Kong.

4. Results

Identifying whether or not bus emissions are significant contributors to roadside air pollution in Hong Kong required several steps. To understand the problem and to draw comparisons, it was necessary to understand the transportation system in Hong Kong. As of 2009, there were approximately 584,070 vehicles in Hong Kong (Transport Department, 2009). This 2009 total includes all forms of vehicular transit: motorcycles, private cars, urban taxis, Lantau taxis, franchised buses, private buses, light goods vehicles, medium goods vehicles, heavy goods vehicles, and others. Our study uses an analysis of commercial diesel vehicles, specifically franchised buses, to demonstrate the relationship between these vehicles' impact on air pollution and subsequently their influence on public health.

4.1. Bus Emissions Contribution to Air Pollution in Hong Kong

There are 117,250 commercial diesel vehicles in Hong Kong, which make up 20% of the total number of motor vehicles (Clean Air Network, 2010a, p.5). In general, commercial diesel vehicles are the main contributors to roadside pollution. They produce 88% of Respirable Suspended Particulate (RSP) and 76% of Nitrogen Oxides (NOx) (Clean Air Network, 2010a, p.6). The distribution of commercial diesel vehicles by engine standard is as follows: Pre-Euro (20%), Euro I (13%), Euro II (24%), Euro III (26%), Euro IV (17%), and Euro V (0%) (Clean Air Network, 2010a, p.5). Each type of diesel contributes to roadside air pollution in different quantities.

Of all the commercial diesel vehicles on the road, this project focused on the franchised buses. In 2010, there were 5,955 franchised buses registered in Hong Kong. Franchised buses constituted 30% of the total number of buses, including franchised buses, non-franchised buses, private buses, and public and private light buses (see Figure 4-1). Franchised buses make up 5%

of commercial diesel vehicles and contribute 6% of Respirable Suspended Particulate (RSP) and 11% of Nitrogen oxides (NOx) on a territorial basis (Legislative Council, 2010). According to Clean Air Network, franchised buses along busy traffic corridors such as Mong Kok, Central, and Causeway Bay contribute 15% of RSP and 26% of NOx (2009). Other estimates exist, however, of the contribution of franchised buses to roadside air pollution. The Legislative Council estimates that 40% of total vehicular emissions are contributed by franchised buses on highly congested roads (2010).

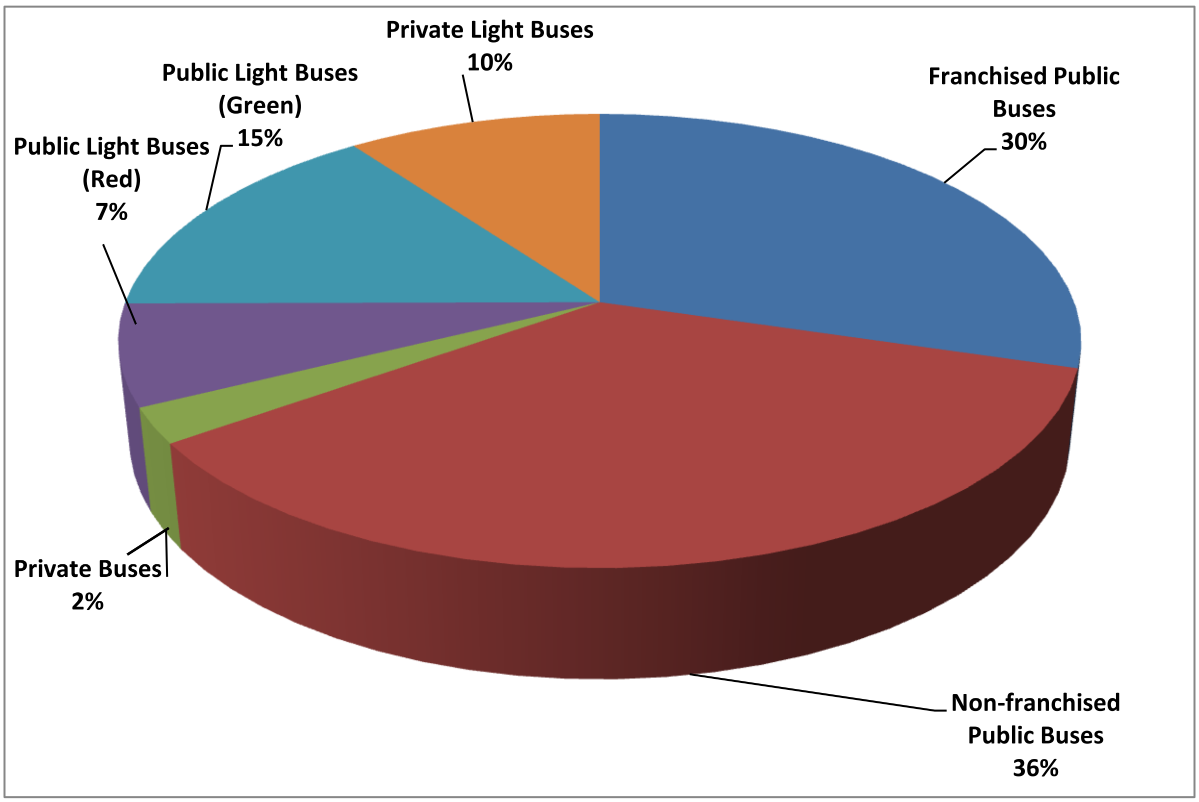

Figure 4-1: Distribution of types of buses in Hong Kong
(Clean Air Network, 2009)

As it is indicated on Figure 4-2 there is still a high percentage (74%) of Pre-Euro, Euro I, and Euro II buses in Hong Kong. Euro V buses make up only 1% of the total number of franchised buses (Clean Air Network, 2010c, pp. 1-2). According to Clean Air Network, in 2011 there are 415 Euro I buses operating within the city, and it will take until 2014 for all of these older buses to be removed (2010c, p. 6). Euro II standard buses will operate until 2018, and Euro III will continue to run until 2025. While Euro III buses will be operating on only 22 buses, which is a small fraction of the total franchised bus fleet, each Euro III bus emits three times more particulate matter (PM) than Euro V buses (Clean Air Network, 2009, p. 17).

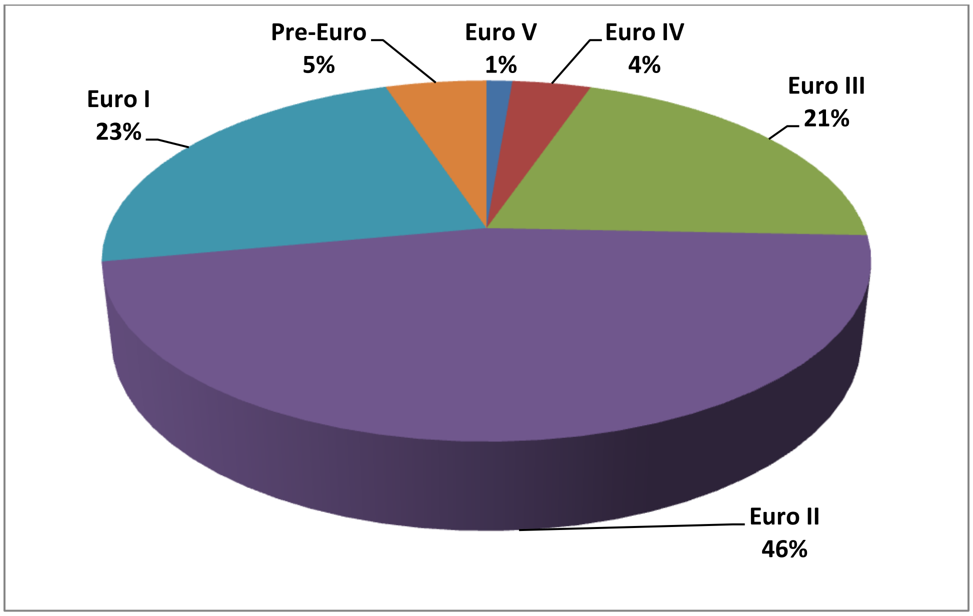

Figure 4-2: Distribution of Franchised buses by Engine standards
(Clean Air Network, 2009)

Along a number of main roads in Hong Kong, franchised buses are used as the primary means of transportation, particularly, Hennessy Road, Nathan Road, and Des Voeux Road. Nathan Road, the largest of these three roads has approximately 130 bus stops while Hennessy Road and Des Voeux both contain approximately 40 bus stops (see Table 4-1). From this, one can see the distance between bus stops is short. Additionally, according to a bus congestion report written by the Legislative Council, during peak hours approximately 30% and 32% of the traffic on Des Voeux Road and Nathan Road respectively is constituted by franchised buses

(Legislative Council, 2010, p. 2). A similar situation of high traffic congestion can be also observed on Hennessy Road in the Wan Chai District (Legislative Council, 1999).

Road Name	Road Length (meters)	Approximate # of Bus Stops	Average Distance between Bus Stops (meters)
Hennessy Road	1600	130	40
Nathan Road	3600	40	28
Des Voeux Road Central	1300	40	33

Table 4-1: Number of bus stops and average distance between stops on main roads

Along the main roads the average distance between the bus stops is very short as shown in Table 4-1. Because the distance is short this increases the number of buses that idle along the road. According to the Clean Air Network's paper on the Motor Vehicle Idling Bill, idling bus engines harm both public health and air quality (2010b). Even Legislative Council has realized the damage from idling bus engines as they state in their 2010 report (Clean Air Network, 2010b).

4.2. Most Polluted Districts and Main Roads

Hong Kong is experiencing elevated levels of roadside air pollution. This project chose to focus on the significantly affected areas of Hong Kong. In a personal interview with Professor Chan of the Hong Kong University of Science and Technology, he directed the team toward data from the Mobile Real-Time Air Monitoring Platform (MAP) study performed by Civic Exchange. The MAP data made it possible to look specifically at the three most polluted roads and the particular districts in which these roads reside or pass through. The roads examined were Hennessy Road of Wan Chai, Nathan Road of Yau Tsim Mong, and Des Voeux Road of

Central/Western. Additionally, data on the three most polluted highways in Hong Kong were used for comparison with respect to traffic volume, NO_2, NO_X, and black carbon. The concentrations of NO2, NOX, and black carbon gathered are averages from a series of map measurements; these measurements were taken at regular time intervals while driving down each of these main road or highway segments (Table 4-2).

Road/Highway	Vehicles/Day	NO_2 µg m^{-3}	NO_X µg m^{-3}	Black Carbon µg m^{-3}
Hennessy Road	24000	479	1320	25.8
Nathan Road	41400	378	1170	24.7
Des Voeux Road Central	13,000	388	1,140	23.9
Average	26133	415	1210	24.8
Tsing Kwai Highway	86900	187	749	22.8
San Tin Highway	71700	122	672	16.4
Tolo Highway	93200	117	638	17
Average	83933	142	686	18.7

Table 4-2: Traffic volume and pollution for main roads and highways
(Lau, Yeung, Lau, & Chan, 2010, pp. 15-16)

The table show that Hennessy Road, Nathan Road, and Des Voeux Road have extremely higher NO_2 concentrations and NO_X concentrations than that of Tsing Kwai Highway, San Tin Highway, and Tolo Highway (see Figure 4-3). Concentrations of black carbon however are only slightly higher on roads than highways (see Figure 4-4).

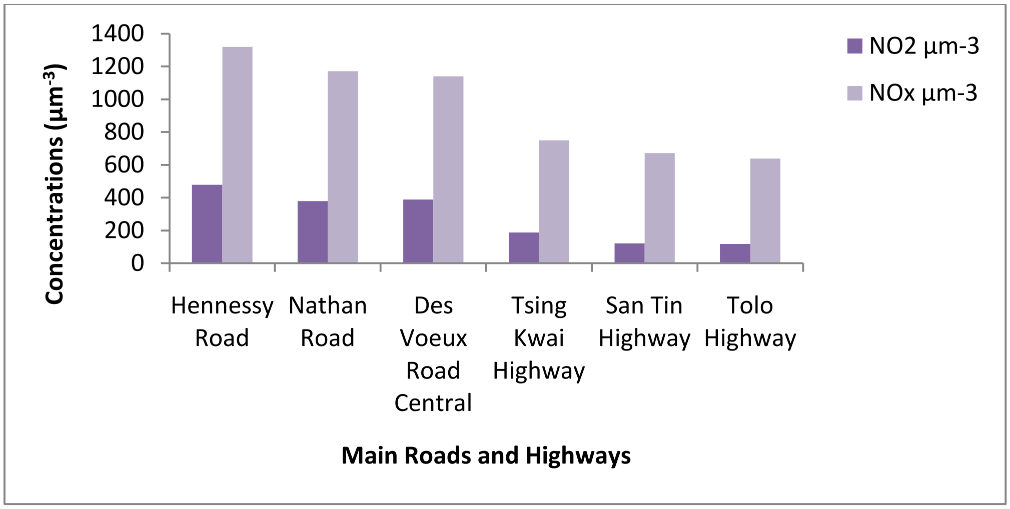

Figure 4-3: Average NO_2 and NOx emissions from main roads and highways
(Lau, Yeung, Lau, & Chan, 2010, pp.15-16)

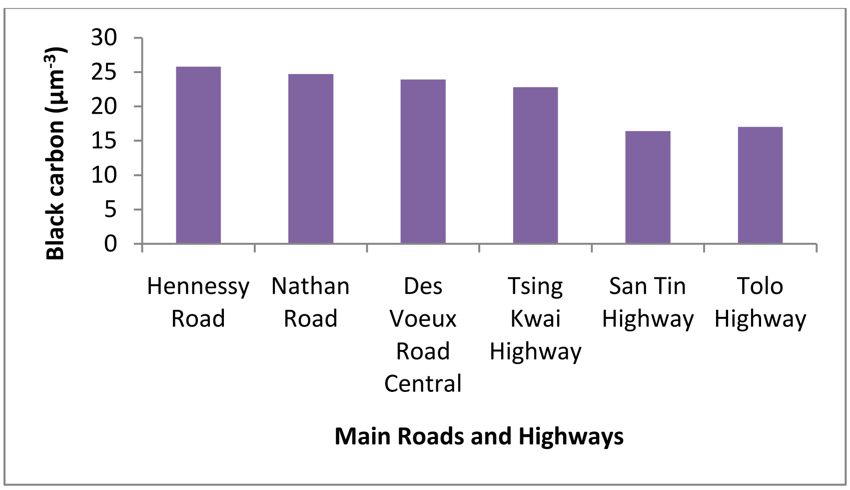

Figure 4-4: Black carbon emissions by main roads and highways
(Lau, Yeung, Lau, & Chan, 2010, pp.15-16)

Conversely, one might assume that high levels of traffic in urban areas correlate directly with higher levels of pollution. This, however, is not the case in urban areas of Hong Kong. By comparing the vehicles per day on highly polluting roads with NO_2 and NO_X concentrations, Figure 4-5 and Figure 4-6 demonstrate that these specific roads have much higher levels of pollution despite their relatively low amount of vehicles per day. Such high levels of pollution are attributable to two things: heavy vehicle traffic and “street canyons”. “Street canyons” also known as “urban canyons” are streets and roads surrounded by tall densely clustered buildings (M. Kilburn, personal communication, 27 January 2011). As vehicles travel through these canyons the emissions from their engines are trapped by the tall densely packed buildings. These buldings block natural airflow and prevent the dispersal of air pollution emitted from engines; this is known as the “street canyon effect” (Loh, Kilburn, & Chau, 2010, p. 4).

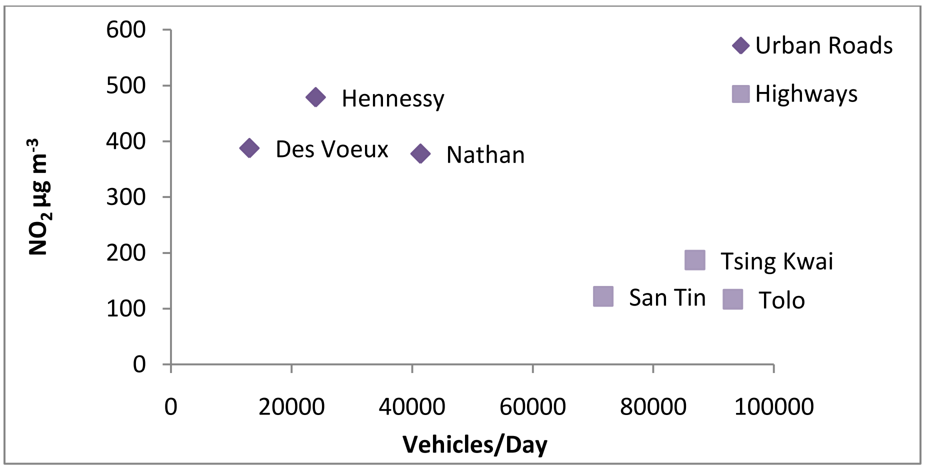

Figure 4-5: NO_2 emissions by vehicles per day by main roads and highways (Lau, Yeung, Lau, & Chan, 2010, pp.15-16)

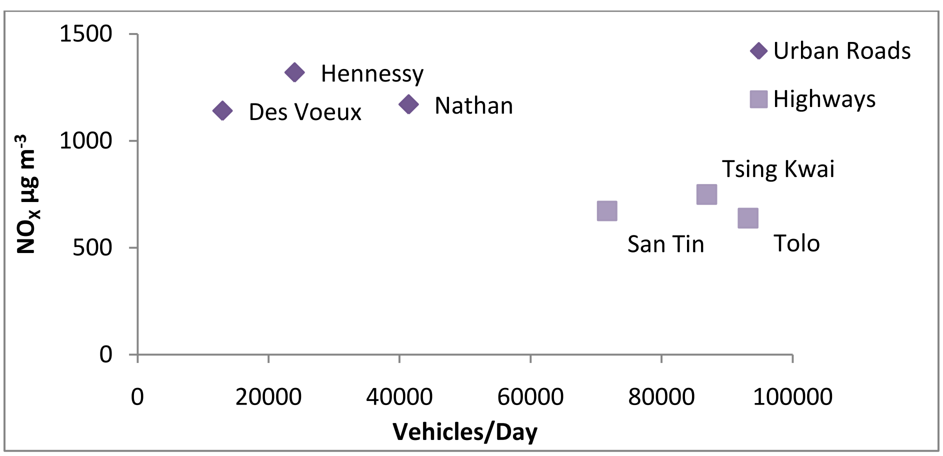

Figure 4-6: NOx emissions by vehicles per day by main road and highway (Lau, Yeung, Lau, & Chan, 2010, pp.15-16)

The reason three highways have significantly lower roadside air pollution than the three roads is that despite their high vehicles per day is the amount of open space surround them. Since highways do not often run through "street canyons", air pollution emitted from engines is able to disperse much easier. This argument is also supported by Civic Exchange:

> "There is clearly no relationship between the pollutants (NOx and black carbon) and traffic density among the arterial roads in urban areas, even if highways are included. Although the urban arterial roads usually have lower traffic densities than do the highways, they are associated with higher mean road segment-averaged concentrations of NOx and black carbon. Similar observations can also be made with the mean road segment-averaged concentration of NO_2." (2010, p.30)

As stated earlier Hennessy Road, Nathan Road, and Des Voeux Road all have extremely high NO_2 levels. When comparing these NO_2 concentrations to the respective district averages, concentrations along these main roads are considerably higher (see Figure 4-7). Figure 4-7 also shows that Hennessy Road, Nathan Road, and Des Voeux, in terms of $NO_{2,}$ are extremely higher than acceptable pollution concentrations for both Hong Kong (AQO - red line) and the World Health Organization (WHO - green line) air quality standards.

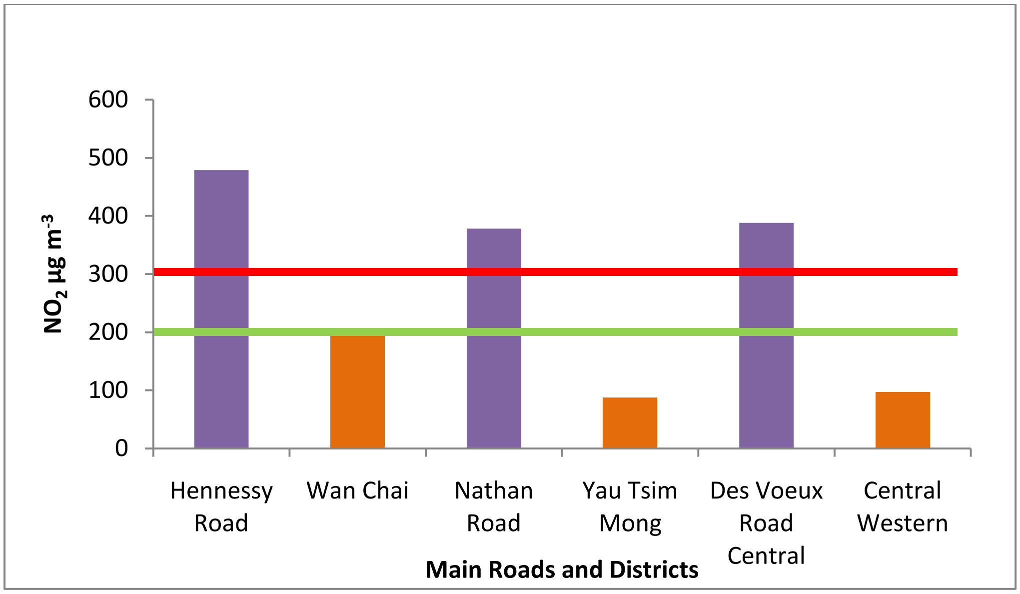

Figure 4-7: District and main road comparison of NO_2 concentrations
(Lau, Yeung, Lau, & Chan, 2010, p.10)

4.3. Population Distribution in Wan Chai, Central/Western, and Yau Tsim Mong

Wan Chai, Central/Western, and Yau Tsim Mong are the three most highly polluted districts of Hong Kong, and these districts encompass three of the most highly polluted roads in Hong Kong. All three areas are also highly populated. The 2006 Population By-Census records have broken down the census data from these three areas into numerous categories to delineate the population (Census and Statistics, pp. 3-4). Wan Chai is a single area of Hong Kong with a population of 39,137 (p. 54). Central/Western encompasses two areas and reflects a larger population than Wan Chai with 250,064 people (p. 56). Lastly, Yau Tsim Mong, which includes the areas of Yau Ma Tei, Tsim Sha Tsui, and Mong Kok, has a population of 280,548 (p.60). In districts with such large populations, demographics vary widely. To facilitate analyzing these districts, they are broken into smaller units which can be measured more thoroughly.

4.4. Public Health Effects of Air Pollution

Studies exist which demonstrate a link between adverse effects from air pollution and socioeconomic status. In particular, the analysis of Social Deprivation Index (SDI) and mortality rates related to air pollution showed that people living in TPUs with high levels of social deprivation experienced greater risk of death from air pollution-related causes (Wong et al., 2008). Additional research indicates a similar relationship between reductions in visibility in Hong Kong and increases in mortality, showing that the adverse health effects of pollution are related to both pollution severity and social deprivation (Thach et al., 2010).

A similar trend was found when analyzing the relationship between the modified Social Deprivation Index (mSDI) used in this project and location of the most heavily polluted roads in Hong Kong. The three mSDI tertiles were all approximately the same size, as can be seen in Table 4-3 and Figure 4-8. Error bars in Figure 4-8 are one standard deviation above the mean and one standard deviation below. Tertiles were well-separated by mean and standard deviation.

	Number of Tertiary Planning Units (TPUs)	**Mean 2006 modified Social Deprivation Index (mSDI)**	**Standard Deviation**
Low mSDI	14	0.0623	0.0086
Medium mSDI	15	0.0898	0.0060
High mSDI	15	0.1098	0.0103

Table 4-3: Tertile size, mean 2006 mSDI value, and standard deviation

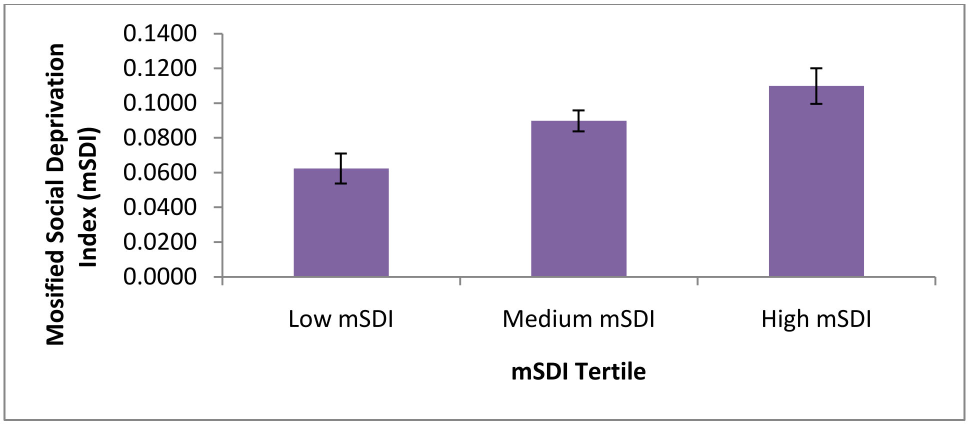

Figure 4-8: Mean mSDI values by 2006 mSDI tertile, with 1 s.d. error bars

Analysis of the locations of the most polluted roads in Hong Kong, namely Des Voeux Road, Hennessy Road, and Nathan road, showed that many of the TPUs through which these roads passed were socially deprived. Only approximately 7% of low-mSDI TPUs contained a segment of any of the roads (see Table 4-4). This is quite low compared to a frequency of 60% for medium-mSDI TPUs and 60% for high-mSDI TPUs (see Figure 4-9).

	TPUs with roads not present	**TPUs with roads present**	**Total**
Low mSDI	13	1	14
Medium mSDI	6	9	15
High mSDI	6	9	15
Total	**25**	**19**	**44**

Table 4-4: Distribution of TPUs containing roads with high air pollution by 2006 mSDI tertile

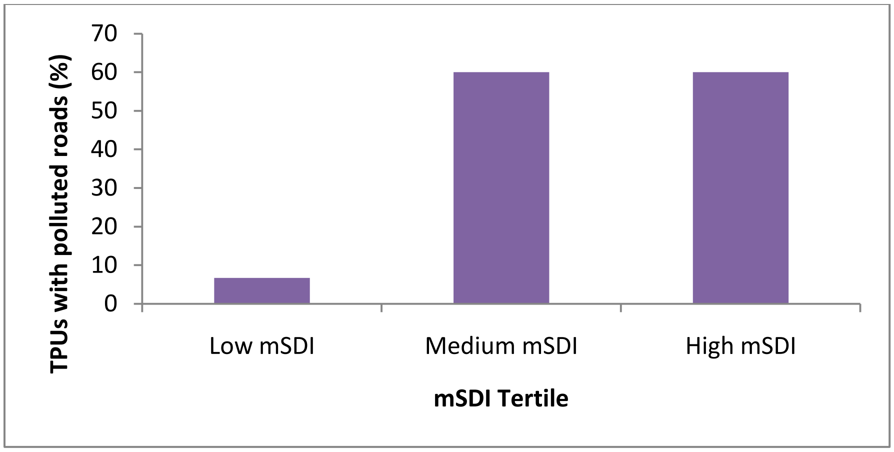

Figure 4-9: Percentage of TPUs containing roads with high air pollution by 2006 mSDI tertile

Testing the distribution of the roads across mSDI tertiles showed that it was unlikely that this result was due to chance. The chi-square test of the frequency distribution of the presence of these road segments across mSDI tertiles produced a p-value of 0.005, which is below the alpha value and statistical significance threshold of 0.05. Thus, the null hypothesis that road segments are distributed uniformly randomly across mSDI tertiles, and thus strata of social deprivation, was rejected.

This result shows that it is probable that a relationship exists between mSDI levels and the presence of the roads with the highest levels of roadside air pollution in Hong Kong. It is important to note that this test only focuses on these roads. However, this analysis provides support for the hypothesis that TPUs which are more socially deprived may be more likely than less socially deprived TPUs to contain roads which have high levels of pollution.

According to the Clean Air Network, Environmental Protection Department (EPD) sensors indicate that Hong Kong is responsible for its own ambient air pollution for roughly 53% of the year (2007). For the remainder of the year, regional pollution sources from outside of

Hong Kong contribute significantly. This is, however, only the role Hong Kong plays in its ambient pollution. At the roadside, urban canyons—dense clusters of buildings alongside streets—trap and amplify air pollution from local sources. These canyons restrict airflow severely, thus preventing pollutants from escaping and being diluted.

A study of the impact of urban canyons on roadside pollution in Hong Kong showed that, in an urban canyon, levels of $PM_{2.5}$ increase exponentially as height from the ground decreases (Zhang et al., 2010). As a result, people who spend more time close to or on the ground are potentially exposed to exponentially higher levels of pollution than those who spend their time higher from the ground. These people at ground level may suffer from adverse health effects due to sustained exposure to such high levels of pollution.

Survey data from roadside workers in Hong Kong further support the claim that higher levels of exposure at ground level lead to problems related to air quality and personal health. A study by the Health Economics Team at the University of Hong Kong (2002) of people who primarily work at the roadside showed that 15% of roadside workers claim to suffer from heart or respiratory conditions, compared to 5% of the general population (see Figure 4-10). Additionally, these workers claimed to be suffering from more coughing and congestion, and perceived that the quality of the air in their home and working districts was lower overall. Roadside workers also generally assessed their health as being lower than that of the general population (see Table 4-5 and Figure 4-11).

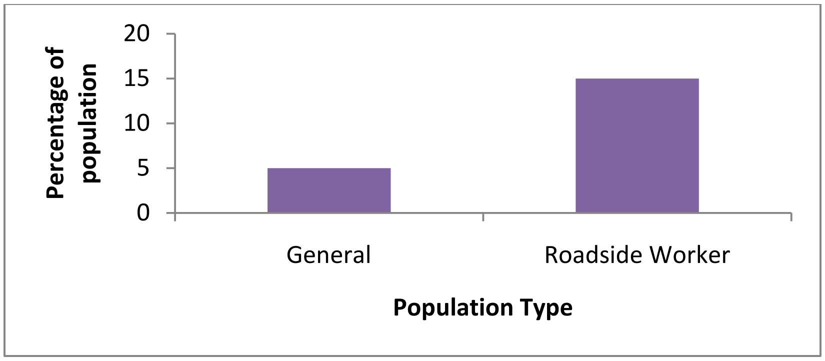

Figure 4-10: Self-reported rate of heart/lung issues in roadside worker and general populations (Health Economics Team, 2002)

Health	General Population (%)	Roadside Population (%)
Poor	3.9	1.7
Fair	40	72.9
Good	35.4	22
Excellent	20.7	3.4
Total	**100**	**100**

Table 4-5: Self-reported quality of health among general population and roadside workers (Health Economics Team, 2002)

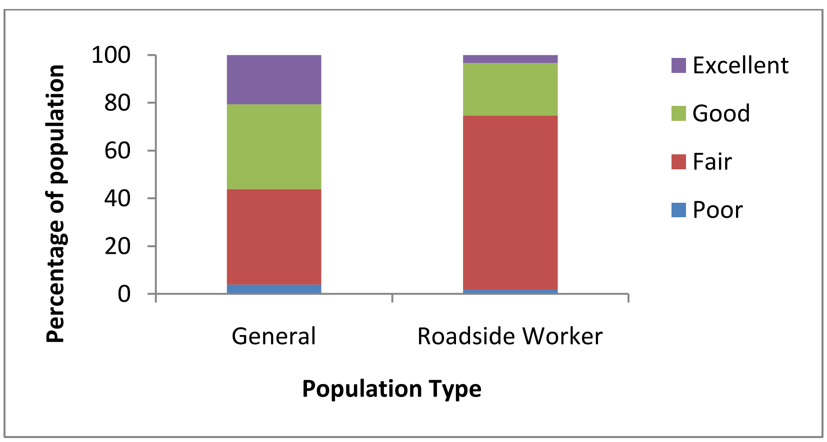

Figure 4-11: Self-reported quality of health of general population and roadside workers (Health Economics Team, 2002)

All of these findings are evidence in support of the hypothesis that vehicular roadside air pollution exposure and socioeconomic status are highly correlated. Higher levels of social deprivation and lower levels of elevation from the ground are both associated with both high roadside air pollution and adverse health effects—including mortality—of pollution exposure. These results have drawn a relationship between franchised buses and their contribution to roadside air pollution; furthermore, it relates that contribution to the public health of people within socially deprived areas of Hong Kong.

5. Conclusions

Emissions from diesel vehicles produce a large portion of roadside air pollution in Hong Kong, an issue which greatly impacts the lives of its residents. Franchised buses are a type of diesel vehicle which suffer from many problems, including poor route planning, lax fuel standards, and predominantly old engine models. As a result, these buses stand as contributors to roadside air pollution in the region.

Not all residents of Hong Kong are exposed to pollution equally, though, and exposure to roadside air pollution and its health effects are an issue tied strongly to social justice and class issues. It was necessary to determine both the contribution of franchised buses to roadside air pollution in Hong Kong, as well as the impact of roadside pollution on socially disadvantaged residents. Chapter 3 discusses the methods–interviews, literature reviews and data analysis–used to achieve the results and conclusions, described in Chapters 4 and 5.

Background research gave insight into local public transport infrastructure, previous efforts by the local government to improve air quality, and issues of class and social justice in Hong Kong. In particular, an understanding of the growth of Hong Kong in recent decades, the impacts of air pollution on the people of Hong Kong, the local bus system, and local air pollution policy successes and failures, as well as issues of social justice relating to air pollution in Hong Kong was needed.

While initially we had expected to analyze all buses in Hong Kong, background research and discussions with experts quickly showed that only franchised buses would be feasible to study. Unfranchised buses are subject to less stringent regulations by the local government, making tracking and analyzing these buses infeasible for this study. In general, however, franchised buses do cover nearly all of the territory of Hong Kong which sufficed for this report.

The three methods used for this study were literature reviews, interviews, and data analysis. Reviews of scientific and legislative literature were primarily used during background research but were also valuable when drawing final conclusions. Interviews, too, provided a wealth of preliminary data, most of which could be supported directly with scientific literature. It was in the interviews that the team's methods were the most flexible. Although each interview was distinct, and not as structured as anticipated, the data and statements from the interviews were extremely useful.

The project reviewed several types of data to understand the links between social class and air pollution exposure, including time-series census data and roadside air pollution data from the District Council Districts of Central/Western, Wan Chai, and Yau Tsim Mong. Analysis of these data, in conjunction with the other research methods used, provided many insights into the contribution of buses to roadside air pollution and the impact of this pollution on disadvantaged residents of Hong Kong.

The study has been important for all team members and the Hong Kong Institute of Education, as well as other local academics and non-governmental organizations with an interest in air pollution and social justice. It is the project team's hope that the results from this project will be useful as a foundation from which further conclusions about air pollution from buses and their impact on social justice may be drawn.

6. Future Research

Due to the broad nature of the project, as well as time and resource constraints, this investigation elected not to explore certain topics within the scope of the problem of bus emissions and social justice. Data on bus routes were not readily available during the time period in which the study took place, preventing an analysis of the relationship between bus route overlap and other variables, such as social class and roadside pollution. A future project exploring the relationship between bus route planning and other topics covered in this study would be useful in understanding further how other aspects of the bus system in Hong Kong, besides the buses themselves, contribute to roadside pollution.

Public health is another topic which the team wished to relate to bus emissions and social justice. Some data currently exist regarding air quality both in buses and at bus stations. Not all of the research the team found, however, directly addressed the public health ramifications of air pollution exposure among people who spend time in buses. A future project could incorporate these and other data into a more in-depth study of the impact of buses on the health of their riders and drivers. Additionally, further research could expand on current research into the health and economic costs of maintaining old buses in Hong Kong.

Air pollution and social justice are two issues which are of great importance to Hong Kong, both currently and in the future. The bus system is just one of many contributors to roadside air pollution in the territory, all of which warrant extensive research. Ultimately, any project focusing on the impacts of local and roadside air pollution on the people of Hong Kong will be of merit and significance.

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Appendix A: Interviewee Contact List

Name	Organization/Institute	Reason for Contact
Professor W.T. Hung	Hong Kong Polytechnic University	Professor Hung has extensive expertise in transportation.
Mr. Mike Kilburn	Civic Exchange	Civic Exchange serves as a prominent policy think tank in Hong Kong.
Professor Chak Chan	The Hong Kong University of Science and Technology	Professor Chan is an expert in the field of air pollution research.
Professor Sarah McGhee	The University of Hong Kong	Professor McGhee is an expert in the field of public health economics, particularly regarding air pollution.
"To whom it concern"	Greenpeace	Greenpeace is a prominent environmental organization worldwide and in Hong Kong.
Professor Bill Barron	The Hong Kong University of Science and Technology	Professor Barron has expertise in sustainable development and environmental issues.
Edwin Town	Clear the Air	Clear the Air is an NGO in Hong Kong which focuses on air pollution.
Joanne Ooi	Clean Air Network	Clean Air Network is an NGO in Hong Kong which focuses on air pollution
William Lam	Hong Kong Polytechnic University	Professor Lam has expertise in traffic planning and management.

Appendix B: Contact Protocols

E-mail Message Protocol

Dear (interviewee name):

My name is (name), and I am conducting a study in Hong Kong with a group from Worcester Polytechnic Institute in the United States. We are looking to determine the impact of buses on vehicular, roadside air pollution in Hong Kong, as well as determine policies which may be enacted to reduce levels of pollution from buses. Given your expertise in (tailor to person), we would like to request a brief meeting with you to learn more about (what we hope to gain from the interview). Please let us know if you would be willing to meet with us.

We will be following this e-mail with a telephone call (later in the afternoon/tomorrow morning). Thank you for your time.

Sincerely,
(name)

Phone Call Protocol

Hi, my name is (name); I'm working with a project group from Worcester Polytechnic Institute in the United States on a study regarding air pollution. I sent you an e-mail (however long ago) requesting a brief meeting with (you/the person we want to interview) to gain some insight into air pollution in Hong Kong, and was just wondering if you had seen it.

(response from other person)

- Check to see what their availability is if they haven't yet mentioned it
- If they're available, figure out the time
- Confirm the address, time, date, etc.
- Thank them

Appendix C: Interview Questions

1. Looking at the current air pollution situation in Hong Kong, can you comment on the public awareness of the matter?
2. How do you think air pollution impacts daily life in Hong Kong?
3. Who or what groups of people do you feel are most affected by the air pollution?
4. Have you looked into or done any research regarding roadside air pollution?
5. How significant of a role do you think buses play in vehicular, roadside pollution relative to other vehicles?
6. Do you have any recommendations you believe the government/EPD should take into consideration regarding air pollution in Hong Kong

Appendix D: mSDI Calculation Tables

	TPUs with roads not present	TPUs with roads present
High mSDI	8.333…	6.333…
Low mSDI	8.333…	6.333…
Medium mSDI	8.333…	6.333…
Total	**25**	**19**

Table 0-1: Theoretical distribution of roads by mSDI tertile, used for chi-square test

District	Tertiary Planning Unit (TPU)	2006 modified Social Deprivation Index (mSDI)	mSDI Tertile	Contains polluted road segment?
Central/Western	1.4.3	0.0670	Low	N
-	1.4.1	0.0727	Low	N
-	1.4.2	0.0784	Low	N
-	1.1.1	0.0881	Medium	N
-	1.1.5	0.0959	Medium	N
-	1.1.2	0.1004	High	N
-	1.1.6	0.1005	High	N
-	1.2.1	0.1143	High	Y
-	1.2.2	0.1143	High	N
-	1.1.4	0.1174	High	Y
-	1.1.3	0.1230	High	Y
-	1.2.3	0.1261	High	N
-	1.2.4	0.1261	High	N
Wan Chai	1.8.1	0.0509	Low	N
-	1.8.2	0.0509	Low	N
-	1.4.0	0.0591	Low	N
-	1.4.9	0.0652	Low	N
-	1.8.3	0.0696	Low	N
-	1.8.4	0.0696	Low	N
-	1.4.5	0.0807	Medium	N
-	1.4.4	0.0838	Medium	N
-	1.3.1	0.0910	Medium	Y
-	1.3.4	0.0970	Medium	N
-	1.3.5	0.0971	High	N
-	1.4.6	0.0997	High	Y
-	1.3.3	0.0999	High	Y
-	1.3.2	0.1051	High	Y
Yau Tsim Mong	2.5.1	0.0543	Low	N
-	2.5.2	0.0544	Low	N
-	2.5.4	0.0562	Low	N
-	2.2.6	0.0585	Low	Y
-	2.5.3	0.0662	Low	N
-	2.1.1	0.0798	Medium	Y

-	2.1.4	0.0799	Medium	Y
-	2.2.5	0.0891	Medium	Y
-	2.2.0	0.0908	Medium	Y
-	2.1.2	0.0927	Medium	Y
-	2.1.5	0.0935	Medium	N
-	2.1.6	0.0935	Medium	Y
-	2.2.1	0.0948	Medium	Y
-	2.2.2	0.0958	Medium	Y
-	2.2.7	0.1004	High	Y
-	2.2.9	0.1080	High	Y
-	2.2.8	0.1146	High	Y

Table 0-2: mSDI value, mSDI tertile, and road presence for all TPUs analyzed

Appendix E: MAP Study

MAP Road/Highway Roadside Air Pollution Data

Road	AADT vehicles d^{-1}	NO_2 $\mu g\ m^{-3}$	NOx $\mu g\ m^{-3}$	BC $\mu g\ m^{-3}$	PN $\#\ cm^{-3}$
Kwun Tong Bypass	96,700	178	496	8.7	28,800
Lung Cheung Road	93,600	205	567	12.9	71,800
Tolo Highway	93,200	117	638	17.0	81,500
Island Eastern Corridor	91,400	180	540	12.3	37,500
Tsing Kwai Highway	86,900	187	749	22.8	59,800
Tuen Mun Road (Tuen Mun)	86,000	179	822	27.2	42,500
Tuen Mun Road (Tsuen Wan)	84,100	175	727	20.9	65,400
Lion Rock Tunnel Road	77,800	122	625	18.8	50,500
Gloucester Road	74,500	217	607	10.9	24,100
San Tin Highway	71,700	122	672	16.4	74,400
Fanling Highway	68,400	105	610	15.9	79,800
Kwai Chung Road	66,800	218	800	20.2	69,600
Kwun Tong Road	65,800	287	924	21.8	51,500
Yuen Long Highway	65,500	120	576	12.6	71,500
Tate's Cairn Highway	58,800	78	416	7.2	31,300
Texaco Road	44,700	180	614	14.4	70,800
Nathan Road	41,400	378	1,170	24.7	29,700
Aberdeen Praya Road	35,900	197	609	14.4	34,500
Po Shek Wu Road	35,800	133	652	25.1	83,500
North Lantau Highway	35,600	91	379	5.7	37,900
Queen's Road East	34,200	251	807	16.1	27,100
Sheung Ning Road	33,000	144	452	4.7	35,900
Container Port Road South	31,200	243	966	30.4	83,900
Ma Tau Wai Road	27,200	320	819	19.8	28,700
Hennessy Road	24,000	479	1,320	25.8	33,900
King's Road	23,800	335	863	17.2	34,000
Hiram's Highway	23,500	92	386	7.5	52,900
Sha Lek Highway	23,300	84	429	4.7	20,900
Po Heung Street & Kwong Fuk Road	22,500	156	556	13.2	35,200
Sha Tsui Road	21,300	180	604	10.8	47,900

Sha Tin Wai Road	20,800	109	427	6.8	23,600
Ting Kok Road	20,800	67	312	3.6	17,400
Sha Tau Kok Road	20,200	110	443	9.0	43,700
Lai Chi Kok Road	19,900	203	560	9.7	33,300
Jockey Club Road	18,700	154	499	13.2	47,300
Aberdeen Main Road	18,500	228	615	18.7	34,300
Queen's Road Central	18,500	212	677	12.4	31,100
Chai Wan Road & Shau Kei Wan Road	17,700	196	525	11.1	27,800
Tuen Mun Heung Sze Wui Road	17,300	172	548	12.2	12,800
Po Lam Road North	17,100	89	390	2.4	17,100
Wylie Road	17,000	100	318	4.1	11,000
Sai Sha Road	16,300	178	552	5.7	24,100
Un Chau Street	15,900	287	706	9.8	37,200
Kam Tin Road	14,000	80	314	6.0	28,800
Kau Yuk Road	14,000	125	436	6.8	39,900
Shun Tung Road	13,400	118	326	4.0	18,800
Des Voeux Road Central	13,000	388	1,140	23.9	50,300
Tin Shui Road	11,900	162	520	8.8	27,700
Canton Road	11,500	182	556	11.2	22,100
Clear Water Bay Road	10,000	83	348	3.9	23,300
Po Fung Road	9,300	77	289	3.2	17,000
Suffolk Road & Kent Road	9,000	123	354	8.1	16,600
Tung Chung Waterfront Road	6,400	77	236	2.3	9,800
Kam Sheung Road	5,500	80	321	4.8	20,800
Luk Keng Road	640	37	203	1.2	7,500

Table 0-1: MAP Study
(Lau, Yeung, Lau, Chan, 2010)

MAP Apparatus used to Measure Roadside Air Pollution Concentrations

Figure 0-1: Mobile Real-time Air Monitoring Platform
(Lau, Yeung, Lau, Chan, 2010)